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TECHNICAL REPORT

Special Report on Lessons Learned (1985-2011) Volume 2: Handbook of Recommended Design Practices (Fire Protection and Life Safely Design Guidelines for Special Purpose Underground Structures)

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14. ABSTRACT: Based on extensive access to over 50 operating underground facilities (UGFs) where fire protection and life safety capabilities were examined as a part of comprehensive survivability assessments, we conclude that existing fire protection codes used in all examined country's UGFs are generally inadequate to serve a large class of special purpose underground structures. Recommended practices to mitigate those inadequacies are discussed in the context of UGF operational constraints and threat effects to include:

- Recommended fire protection design practices
- Recommended life safety design practices

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Underground Facilities (UGFs)	Unified Facilities Criteria (UFC)	WMD Effects	Balanced Survivability Assessments
Underground Structures	Authority Having Jurisdiction	Ground Shock Effects	Underground Vulnerability Assmnts
Fire Protection Design Guidelines	Lessons Learned	Electromagnetic Effects	Fire Protection Engineer (FPA)
Life-Safety Design Guidelines	Recommended Practices	C3I/C4I Missions	Operational Constraints

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PREFACE

DTRA and its legacy organizations conducted studies to support designs of special purpose underground facilities (UGFs), conducted comprehensive Balanced Survivability Assessments (BSAs) and Underground Vulnerability Assessments (UVAs) of over 50 operating UGFs. Fire protection and life safety were evaluated in all those efforts. Contributors to this volume's draft participated in almost all of those efforts. In each UGF assessed, contributors had access for at least one week to the fire protection systems, life safety features and operations. There is now a two-fold imminent loss of contributor's experience**:** 1) they are retiring or becoming unavailable and consequently are taking 25+ years of damage control and fire protection assessment experience (1985-2011) with them and 2) opportunities to replicate their experience no longer exist because many NATO and former Warsaw Pact (WP) UGFs have been closed. Before the value of that experience is lost, DTRA/RD-CXA directed that lessons learned be developed from the perspective of their effect on operational readiness to control fires in UGFs. And, where weaknesses were found, develop recommended practices based on those lessons for review, comment and consideration in DoD for improving design criteria for a special class of UGFs.

Lessons learned in Volume 1 make a case for developing stronger fire protection design guidance in DoD's Unified Facility Criteria (UFC) or in other appropriate publications including proposing a class of UGFs defined as "Special Purpose Underground Structures." DTRA proposes that *Special Purpose Underground Structures* be defined as "Below grade structures designed to provide mission survivability and endurance against blast and WMD effects."

Recommended practices are based on operational effects they would have on UGF mission and structural survivability. The objective is for fire protection and life safety to provide damage and casualty protection consistent with the design purposes of DoD's UGFs. Each recommended practice seeks to improve on fire protection weaknesses found in special purpose UGFs, whether those UGFs are U.S., Allied or former WP nation's UGF. There was something to be learned in every facility whether friendly or former enemy. These recommended practices are not so much technically based as operationally based. That is, the operational basis depends on how the recommended practice would affect the ability of UGF operators and occupants to control a fire when outside assistance is not available. **Recommended practices provided in this Handbook do not supersede or replace authorized official codes or the UFC**. However, the recommended practices can be used to elevate minimum requirements to a protective level that is more consistent with a UGF's mission, threat effects and operational constraints.

Recommended practices cover a wide range of design topics related to fire protection and life safety with special Ground Shock Protection and Electromagnetic Pulse (EMP) Protection sections. Angelo Cicolani is principal author, Mike Brodeur developed and presented the initial briefing about this effort at the Hardened Facilities Manager's Conference at Cheyenne Mountain Complex in October 2011, Tom Neighbors, PhD developed Electromagnetic Pulse parts of the Handbook and Dwayne Piepenburg, PhD, PE developed Ground Shock parts of the Handbook. Reviews and comments that contributed significantly to improving the draft version were provided by Jay E. Bordwell, PE (Fire Protection Engineer, NAVFAC Washington), Kevin L. Barnes (Fire Chief, Raven Rock Mountain Complex) and Chris A. Miller (Fire Chief, Cheyenne Mountain Air Force Station).

CHAPTER 1: HANDBOOK OF RECOMMENDED DESIGN PRACTICES for SPECIAL PURPOSE UNDERGROUND STRUCTURES

1.0 SUMMARY

The authors conclude that the fire protection installations in DoD Underground Facilities (UGFs) that they examined over the previous 25 + years are inadequate to protect them under effects imposed by their common Weapons of Mass Destruction (WMD) design threats and constraints imposed by the operational hazards to which they would be subjected. Volume 1 discusses the issues and causes of that inadequacy and proposes a potential solution. Volume 1 also provides the operational context and constraints in which the fire protection engineer's (FPE's) designs must operate. This volume takes the process one step further and identifies where code additions are needed, where existing codes need stronger emphasis and where existing codes need to be modified in order to better serve a class of U.S. UGFs defined as "Special Purpose Underground Structures." We propose that *Special Purpose Underground Structures* be defined as "Below grade structures designed to provide mission survivability and endurance against weapon blast and WMD effects." The primary emphasis is to propose how to make fire protection and life safety installation damage resistant to weapon blast and WMD effects. Code additions, not here-to-fore published in fire protection codes are discussed in separate sections for Ground Shock Protection and Electromagnetic Pulse (EMP) Protection.

1.1 Objectives

The **objective** of this volume is to document a model of fire protection and life safety design guidelines from which additional Unified Facilities Criteria (UFC) guidance may be developed. Because the missions protected in these facilities are important, the first fire protection priority, when life safety and structure are not at immediate risk, is to preserve their mission capability.

In the absence of authoritative and comprehensive fire protection design guidance for this unique and large class of structures, these guidelines offer an interim basis on which individual UGFs may develop site-specific fire protection goals. To meet the objective, a goal of these guidelines is to protect the missions, occupants and structural integrity of Special Purpose Underground Structures from fire during any operating condition and to improve the survivability of the fire protection system so that it is more consistent with survivability of the structure and other WMD protective systems. Best use of these guidelines is when modernizing or renovating an existing UGF or when designing a new one. Another goal, which departs from most existing codes, is to elevate the importance of protecting mission equipment and continuity of the mission to that of protecting the structure. This closely parallels the purposes of the National Fire Protection Association (NFPA) Standard 76, "*Standard for the Fire Protection of Telecommunications Facilities*". Specifically, these proposed guidelines would provide fire protection resources for the facility staff to fight UGF fires alone when outside assistance cannot respond, i.e., during closed-door operations.

1.2 WMD Effects

The following briefly summarizes ground burst nuclear weapon effects as they may affect fire protection and life safety. Generalized effects of a 10 kiloton improvised nuclear device are described in Scenario 1 of the final draft *"National Planning Scenarios",* 2006 published by the Department of Homeland Security (DHS). It is available online. A general effects tutorial for other WMD events is found in scenario 2 through 15 in the same DHS publication.

There are two primary WMD effects that directly affect the survivability of fire protection and life safety systems in UGFs; ground shock and EMP. Those systems shall meet ground shock and EMP protective requirements for their facility. Architect & Engineer (A & E) firms and FPEs may not know how to design to these requirements and will need coordination with specialists. Protection against ground shock requires that design of hangers and supports for fire pumps, fire mains, sprinklers, smoke exhaust ducts and so on need to be coordinated with a structural dynamics engineer. This is because anchor, hanger and support designs derived from seismic zone requirements, commonly used by FPEs, are not adequate to counter the accelerations and ground motions that accompany a WMD attack. Flexible couplings are needed at many locations to mitigate the effects of asymmetric ground motion that can rupture piping and duct systems. EMP effects result from HEMP (High Altitude EMP) or SREMP (Source Region EMP). The threat in National Planning Scenario 1 is a ground burst which is accompanied by SREMP. For our purposes, HEMP or SREMP effects on fire protection systems are essentially the same, the term EMP sufficiently describes this threat. Protection from EMP effects requires that piping, ducting, HVAC and damper controls, detection and alarm components and system designs all be coordinated between the A & E staff, FPE, Authority Having Jurisdiction (AHJ) and an EMP protection engineer. That is because these systems, if inadequately protected, can experience large voltage and current transients and thus fail and/or cause other systems to fail during an EMP event. FPE and AHJ may need to adjust to use of components that are essential for EMP protection but that are not listed for fire protection and life safety (e.g., fiberglass fire main sections and shielded doors). These topics are discussed in Sections 2.9 (Ground Shock Protection), Section 2.10 (EMP Protection) and in Appendix A, (Electromagnetic Effects).

Two other WMD effects indirectly, but significantly affect fire protection and life safety options for operating in a UGF**;** firestorms and ground obstructions. While research has characterized some of the factors that sustain firestorms, the science is not well understood. UGF owners and A & E firms should consider firestorm effects whether their UGF is in an urban environment or in a remote location surrounded or covered by brush or forest. Firestorms not only prevent external assistance from reaching a UGF, they also prevent evacuation. In addition, firestorms generate superheated air and smoke which can destroy internal equipment, clog filters and so on if ingested into a UGF's ventilation system. Ground or route obstructions prevent or seriously delay the arrival of external assistance. There is a variety of possible obstructive events along access routes**;** e.g., radioactive fallout, craters, debris, destroyed roads, fire and smoke, fallen trees and buildings, Bio or Chemical contamination and debris directly blocking an entrance. Some WMD effects destroy the vehicles on which external emergency response depends. These effects result in conditions that external response teams cannon traverse, should not be counted on for rapid response and that constrain a UGF's operational options.

1.3 Scope & Limitations

<u>The recommended practices provided in this Handbook do not supersede or replace authorized official codes or the UFC.</u> In most cases, guidelines amplify application of those codes and the UFC where guidance for designing damage-tolerant fire protection and life safety systems is nonexistent or the protections to enhance their survivability need to be more specific.

Individual guidelines are shown in bold print immediately followed by supporting discussion. The discussions provide a rationale that FPEs may use to counter and resist budget pressures to install the lowest common denominator type of protection that “meets code” if the code-based protection does not support UGF mission survivability under operational constraints. The guidelines are descriptive, i.e., they are not written in the succinct language of codes, but state a guideline followed by a discussion about the circumstances that caused the guideline to be included. The guidelines follow the traditional uses of the words “must’, “shall”, “should”, etc. found in most building codes. When shall is specified, it is intended that the stated requirement will not be optional for special purpose underground structures. Site-specific design approval is always the purview of the FPE and owner responsible for each UGF project.

The scope includes guidance about which WMD effects are most likely to cripple fire protection and life safety systems and what sort of design features are needed to protect those systems from WMD inflicted damage. Each guideline in its own way illustrates the range of potential vulnerabilities found in UGFs. That range of vulnerabilities is reflected in the diversity of guidelines all of which are meant to mitigate some issue found in more than one UGF.

The design guidelines are derived from best practices observed throughout the world-wide assortment of UGFs assessed by DTRA. The proposed design guidelines are not intended to over-design or “gold plate” fire and life safety protections in Special Purpose Underground Structures. The guidelines are proposed to better balance the protections for fire and life safety systems with the weapon blast and WMD protections installed for other systems and also to install systems that are consistent with the criticality of missions protected in DoD’s UGFs.

For purposes of brevity “*special purpose underground structures*” of concern to this Handbook may be abbreviated as "UGFs", “special purpose UGFs” or “C4I UGFs”; these terms are interchangeably used throughout this Handbook. Fire protection and life safety designs discussed in this Handbook also apply to ancillary structures that connect with or support UGFs.

There are few references concerning fire effects on rock and concrete. The most comprehensive reference for the current state of knowledge is “*Fire in tunnels and their effect on rock*”, a review by Kristina Larsson, published by Lulea University of Technology, Sweden in 2006 and available online. From my review of other online information and as described in Kristina Larsson’s review of available references, the effects of fire on rock and concrete are not well understood by the tunnel or UGF community. Neither concrete nor rock transmit heat well which means that bunkers and tunnels essentially become ovens in which fire heat is reflected back into their spaces. Deadly fires that have occurred in European transportation tunnels have generated considerable research interest. Multiple references and Kristina Larsson’s review conclude that the effects of fire on concrete are better understood than its effects on rock. In

general, it can be said that fire will cause concrete to spall, sometimes explosively depending on the specific type of concrete, the amount of moisture it contains and its fiber content. A layer of shotcrete over concrete liners generally provides good fire protection for the liners. Rock has more variables associated with its stability in fire than concrete. For example, how the rock was excavated (i.e., drill & blast, road header, tunnel-boring machine), how it is supported (i.e., no support, rock bolts, rock bolts plus metal fabric or concrete liner) determine how heat will penetrate and dislodge overbreak portions of the rock face.

Higher maintenance costs are a limitation of increasing fire protection levels and designing those systems to survive WMD effects. Other protective systems, i.e., shock, NBC and EMP protection, designed to function in a WMD environment already incur increased maintenance costs. Those costs are the price of increasing reliability and survivability of protective systems so that a UGF can stay in business during extreme events. UFC 3-601-02 (September 2010) *"Operation and Maintenance: Inspection, Testing, and Maintenance of Fire Protection Systems"* provides the basic guidance of what and how often fire protection systems should be tested.

CHAPTER 2: FIRE PROTECTION DESIGN GUIDELINES

2.0 APPROACH

The approach for writing these guidelines is to protect the mission, occupants and structural integrity of Special Purpose Underground Structures from fire during any operating condition, particularly a closed-door condition, and to improve fire protection system survivability so that it is more consistent with structural survivability. This approach departs from the approach of most existing codes, and elevates the importance of protecting mission equipment and service continuity to that of protecting the structure. The approach draws from a variety of existing sources to include additions to existing criteria, emphasis on, or upgrades to, existing criteria and commissioning or acceptance test practices to improve the effectiveness of commonly installed fire protection systems. Where necessary, new criteria were written to address specific conditions that existing codes do not address. Some of the guidelines strengthen or restate existing code protections, i.e., they raise the bar on minimum requirements (e.g., from "should" to "shall") as they apply to UGFs. Other proposed guidelines add damage-tolerant features, not found in existing codes that are designed to ensure that fire protection capabilities survive when a UGF is subject to either an industrial accident or attack damage. In all guidelines, the notion that outside emergency services may not be able to enter and render assistance is what elevates the guideline above existing minimum requirements. In the absence of authoritative fire protection design guidance for this unique and large class of structures, these guidelines are meant to offer an interim basis on which individual UGFs may develop site-specific fire protection goals.

These guidelines include minimum requirements for mission protection as well as robust fire protection and life safety designs. "Robust" means minimum requirements for these systems are expanded to reduce their vulnerability to industrial accidents or attack damage. A robust three-tiered fire protection system described in Volume 1 (i.e., significantly increased number of fire extinguishers over NFPA code requirements, room-flood clean agent suppression system and sprinklers) should be applied primarily to critical mission spaces. In these guidelines, the

inclination to define every space as critical is strongly resisted and restricted to those spaces without which the Commander cannot perform his mission.

2.0.1 Exceptions

There are few significant differences in early phase fire growth dynamics between above ground structures and UGF structures with the exception of three cases.

- If a UGF has an open-ended passageway (e.g., a vehicle tunnel that is open at both ends), any fire in that passageway will act like a fire in a road tunnel where its slope and natural air drafts dominate how the fire propagates. If that passageway is also an evacuation route, FPEs should tailor the protections and life safety features to the unique fire dynamics that threaten transportation tunnels. Refer to NFPA 502, "*Standards for Road Tunnels, Bridges and other Limited Access Highways*" and some of the newer European literature such as "*The Handbook of Tunnel Fire Safety*", first published by Thomas Telford Ltd., UK in 2005.

- If a UGF has individual buildings within its tunnels, each building should be designed as a separate hazard entity with robust barriers to prevent propagation of hazards from one building to another or to the common tunnel areas. Individual buildings should be designed for extreme events, including extreme fire events. Some design threats could lead to ignition of large fire loads (e.g., POL) from unexpected sources or progressive damage such as short circuits caused by fallen rock, consumables toppled from the tops of equipment onto ignition sources and so on. Refer to "*Extreme Event Mitigation in Buildings: Analysis and Design*", first published by NFPA in 2006.

- If a UGF has vertical shafts, whether for access, ventilation, exhaust, cable bore-hole or raceway, those shafts can act as fire chimneys. If any shaft is also an alternate evacuation route, FPEs need to provide fire escape features, as required by NFPA 101, "*Life Safety Code*" that the physical constraints of the alternate route can accommodate. Elevator designs also need to include fire protection features to prevent them becoming chimneys and to allow their use to evacuate incapacitated individuals.

2.1 FIRE ZONES

Defining fire zones is a means by which an entire facility is compartmented based on fire protection and life safety. Fire zones are the classic passive fire protection system. Boundaries of fire zones are the interior equivalent of a fire break, i.e., fire should not be able to expand across the boundaries. Therefore, the fire rating of zone boundaries are typically greater than the walls of spaces within the zone and special rules pertain to how all penetrations across the boundary (e.g., doors, pipes, ducts, wiring and so on) are to be protected in order to prevent the migration of fire and smoke across the boundary.

2.1.1 All UGFs shall have more than one fire zone.

Discussion. Some smaller UGFs have no fire zones except the structure itself, which is implicitly considered one large fire zone. UGFs should be divided into at least two fire zones. There is no limit to the maximum number of zones; just as long as there are at least two explicitly defined zones. Each fire zone shall have its own means of egress or be able to egress through no less than two other fire zones. For example, if a UGF has two fire zones, each zone shall have a separate means of egress. If a UGF has three fire zones (1, 2, & 3), and for illustration zone 2 is located between zone 1 & 3; zone 2 does not need its own means of egress as long as its occupants can exit through either zone 1 or 3. Generally, fire zones should be limited to no great than about 25,000 ft^2 (~2320 $meters^2$). "Generally" means that the allowable maximum depends on the specific use. For example, a UGF aircraft or ship shelter or drydock requires larger open floor plans than C4I spaces. The allowable space for such unusual fire zones should be evaluated by the AHJ on a case-by-case basis during the design phase. l In addition to the role that fire zones traditionally play, they have an added function in UGFs of protecting critical redundant equipment from the effects of spreading or progressive damage. Appropriately configured and equipped fire zones also permit occupants an option to remain in the UGF when a fire occurs during closed-door operations. Subsequent guidelines discuss why the layout of fire zones in a UGF also drives other considerations for damage tolerant designs. Where the UGF has more than one floor, the floors shall be separated from each other by no less than a two-hour fire barrier. Where redundant critical equipment can be separated, they should be located in separate fire zones.

2.1.2 At least one fire zone shall be designed to function as an internal safe refuge.

Discussion. This guideline supports the ability to shelter-in-place. Ideally, a UGF should have two safe refuges. If at all feasible, safe refuges should be protected by four-hour fire walls and in any event no less than two-hour walls. Understand that occupants could be in the refuge for hours or days before they can be rescued or it is safe to evacuate. Therefore, a safe refuge should be designed and equipped with life safety provisions for extended endurance, as discussed in Chapter 3. In large UGFs, (herein defined as a gross floor area greater than 50,000ft^2/~4640m^2 within the boundaries of blast protection) UGF owners should consider outfitting two fire zones as shelter-in-place safe refuges. If there are alternate or secondary locations to monitor and control critical systems (e.g., Heating, Ventilation and Air Conditioning (HVAC), power, Decontamination (DECON), security, fire alarms and atmosphere control), they should be located in one of these zones. Note that NFPA 520, "*Standard on Subterranean Spaces*" uses the term "refuge area" which "...serves as a safe haven for all people in a subterranean space when evacuation from the space is not possible". Thus, even the civilian and commercial codes designed for facilities that do not expect to be attacked, recognize and provide for the possibility that evacuation may not be feasible.

2.1.3 Fire zones should be coordinated with HVAC zones.

Discussion. Fire zones need to be coordinated with HVAC, CBR and Control Room planners so that air pressure and smoke control can be managed in a coherent manner and alternate facility control stations can be sited in separate fire zones. When fire zones are not coordinated with the initial installation of HVAC, it may be difficult to later modify or install an effective smoke control system. Each fire zone should have HVAC, smoke control, ducts and dampers that can be

operated to isolate it from those of other fire zones. The HVAC system should be designed so that an Air Handling Unit (AHU) either ventilates only one fire zone or can be partitioned by fire and smoke dampers in an emergency to ventilate individual fire zones. If an AHU ventilates more than one zone and its air distribution cannot be partitioned, then containing smoke in the smallest feasible area will be undermined. See Section 2.13 (Smoke Control) for additional discussion.

2.1.4 All fire zone boundaries shall have no less than two hour walls.
Discussion. A one hour wall is not considered a fire zone of any consequence in a UGF because it offers little protection to preserve the mission located in adjacent spaces or life safety when there may be no option to leave the facility. This guideline does not prevent the use of one hour walls within fire zones.

2.1.5 Fire zone walls should have prominent signage indicating that they are fire boundaries.
Discussion. Mission and relocation staffs are almost universally unaware, and indeed frequently unconcerned, that when they run a cable or interim ventilation duct through a fire wall the boundary will be compromised. When queried, their rationale is frequently that the mission is more important now and that reestablishing the integrity of fire walls can be dealt with later. And, then it gets forgotten. This is a serious configuration control issue found in almost all UGFs. The boundary walls of all fire zones should display prominent signage indicating that any penetration must be approved to meet the same fire rating as the barrier being penetrated.

2.1.6 Fire zone doors that may be left open should be controlled by magnetic releases.
Discussion. Again, mission and relocation staffs are frequently too occupied with getting the mission done, particularly in a mission emergency. Closing manually operated doors is not their priority. Magnetic release doors enhance the reliable closure and integrity of fire boundaries. All fire doors should have closure devices.

2.1.7 Emergency generators should be protected by four hour fire walls.
Discussion. Fires in generator rooms are likely to be class B or C fires; they can be very hot for extended periods if they cannot be controlled quickly. Where no fire wall separates one generator from another, the entire generating plant is at risk to a single fire event. Emergency generators are typically diesel driven and are frequently collocated to minimize the length of air- intake and exhaust ducts, as well as to minimize the cost of excavated space. Separating generators by individual four-hour fire walls is the preferred option because that reduces their vulnerability to a single fire. When two or more generators are installed in a single fire zone, separating them by fire walls at a later date is a difficult challenge that may not be practical.

Protecting one generator from progressive damage due to fire in an adjacent generator requires design flexibility. Where a permanent fire enclosure is not practical, some facilities have used drop-in-place fire curtains. Another option is to install firewalls between generators, but to leave their ends open for ease of monitoring. The open ends can be protected with fire doors or curtains that drop in the event of a fire to isolate each generator in its own mini fire zone. When it is not practical to separate generators with fire walls, then fire-extinguisher and room-flood protection needs to be particularly robust. This was accomplished in several NATO facilities

where large extinguishers (each with 25lbs/~10kg or more of agent) were positioned permanently about 4-8 feet (~1.2-2.4 meters) from the front and back of each generator.

Generator fire zones should be protected by automated clean agent fire suppression systems backed up by water. While foam (i.e., Aqueous Film Forming Foam (AFFF)) systems are frequently used for class B hazards (POL), they require a lot of maintenance. If not properly maintained, foam will corrode any ferrous material that it contacts. Even if the generator is not physically damaged by fire, it may not be operable if AFFF came in contact with its digital controls.

2.1.8 False or raised floor panels should normally not be fixed in place with any type of fastener.

Discussion. False floors are commonly used to store spare parts and burnable materials such as cardboard boxes even though NFPA 76, *"Standard for the Fire Protection of Telecommunications Facilities"* strongly cautions against storage of combustible materials in telecommunications facilities. Dust and construction debris accumulate under false floors and generally, false floors also contain power outlets and connections that can become ignition sources in proximity to the described fire load. This potential fire hazard is exacerbated because cooling units also use under floor space to force cooling air up into electronic equipment racks and thus, can feed fresh air to an incipient under floor fire. Screws and other types of fasteners used to fix false floor panels in place significantly slow down access and impede the quickest possible suppression of incipient under floor fires. Thus, false floor panels should be quickly and easily removable. Tools to quickly remove floor panels (such as tile pullers) should be located at each entrance. This topic is also discussed in Section 2.3 (Smoke, Heat and other Detectors). In this guideline, the word "normally" refers to spaces that are not expected to experience ground shock. Where ground shock protection requires floor panels to be fixed, see Section 2.9 (Ground Shock Protection).

2.1.9 The boundaries of EMP protected enclosures should be considered as fire zone boundaries.

Discussion. An EMP protected enclosure, such as a six sided welded steel volume or vault, is essentially a closed steel box with EMP protection at the boundaries for all penetrations. Each penetration protection is designed to strict EMP protective standards. Example penetrations include personnel entry, air, water, and communications, and sensor lines for equipment monitors and fire/smoke detectors. The primary device used to provide EMP protection for some penetrations is a wave guide below cutoff (WBC). Each vault will usually contain its own clean agent and/or sprinkler systems. The fire protection for the vault's steel walls, WBC, EMP entry ways with radio frequency (RF) protective doors, and other critical protective features at the EMP enclosure boundary should comply with the required fire rating for the zone. The closed steel box of an EMP vault presents its own issues because the steel sides are not fire rated. However, they are critical for EMP protection. Specifications for joint EMP/fire protection, which require special attention, are discussed in Section 2.10 (EMP Protection). Depending on the size of the EMP protected enclosure, it may be an independent fire zone within a larger fire zone or, as in the case of a free standing steel building, the interior may contain multiple fire zones. WBCs require special firestop treatment to prevent the firestop from compromising the EMP integrity of any EMP/fire zone boundary. See Section 2.10 (EMP Protection) for guidance.

2.2 CONSTRUCTION MATERIALS

The fundamental approach to construction materials is that they should not add to the fire load. This common sense statement has been egregiously violated in more than one UGF. To illustrate, in one C4I UGF, instead of the customary gypsum drywall, the wall material throughout was untreated chip-board which added thousands of square feet of unnecessary fire load. And, to illustrate the wide variety of FPE opinions in practice on construction materials, in another C4I UGF, all interior walls were 4inch (~10cm) thick light weight concrete. UGFs generally contain elevated fire loads because of their need to store material and POL necessary to sustain their endurance requirements. Other, more acceptable substitutes from customary fire wall materials were light-weight concrete board and calcium silicate wall board.

2.2.1 Burnable materials shall not be used in the framing, supports, exterior walls, basement floor, roof and environmental coverings of buildings constructed inside a UGF. Noncombustible materials shall be used in the construction of walls, fixed partitions, insulation, ceilings, floors and furnishings. Walls, ceiling finishes and movable partitions should conform to the requirements of NFPA 101, "*Life Safety Code*" with the following additional features.

- **Interior finish should be Class A only with a flame spread rating not to exceed 25 and a smoke development rating not to exceed 50 when tested in accordance with NFPA 255, *"Standard Method of Test of Surface Burning Characteristics of Building Materials"*** (See "Cautions" after Discussion that follows).
- **Cellular plastics should not be used as interior wall and ceiling materials. Foam grid panel drop-out ceilings should not be used.**
- **Carpeting and other textile wall coverings should only be applied as an interior finish if the material passes the acceptance criteria of the Uniform Building Code Standard 42-2, *"Test Method for Textile Wall Coverings."***
- **Office, sleeping, eating area and break-room furniture should be of metal construction, except metal frame chairs with integral seat cushions may be used.**
- **Metallic plumbing and conduit should be used.**

Discussion. Fire load is one of the biggest vulnerability factors in UGFs. It is almost impossible to prevent consumable supplies such as instruction books, cardboard boxes and many other paper products from entering a C4I UGF. If this material is ignited, but is not in close proximity to building materials and furnishings that could sustain or enlarge a fire, an incipient fire will be a lot easier to contain. The objective is to keep the construction material from adding to the uncontrolled fire load. Mission and relocation staffs are frequently unaware that fire-retardant and fire-resistant materials are not fire proof, and that many treated furnishing will emit toxic fumes if burned. The toxic fumes will remain in the UGF until they are forcefully removed; there is no option for breaking windows to induce cross-ventilation to clear smoke and fumes. Under closed-door conditions it may not be possible to remove smoke and toxic fumes if the threat prevents make-up air from being brought into the UGF. While toxic-fume producing plastics and other materials may be acceptable in an office building where the occupants can evacuate, they are not acceptable given the worst-case UGF condition that the designer must consider. It is recognized that selection of furnishings for high-level leadership may be prioritized on appearance and comfort with little consideration for their fire retardant qualities. These furnishing should be kept to the absolute minimum, primarily limited to a single top leadership

conference room and quarters. They should be identified specifically in AHJ waivers in order to maintain configuration control of the fire load.

Cautions: Class A interior finishes can have a broad range of smoke development criteria (from 0-450). While the interior finish guideline is specific in its flame spread and smoke development goals, some building products may not be available in a smoke development rating as low as 50. Office and other furniture is made in a wide variety of combustible and fire retardant materials. Fire departments have come to expect that contemporary furniture, whose cushions are made with synthetic materials, burn faster and with more toxic byproducts than those made with organic materials such as cotton or wool that were prevalent in an earlier era. While specifications in original designs can limit the introduction of combustible furniture, the reality is that over time occupants have and will continue to replace original metal furnishings with more appealing but burnable furniture unless there is a strong configuration control program.

2.2.2 Electrical and data/communications cables shall comply with the requirements of NFPA 70, "*National Electrical Code*", with the following additional requirements.

- **Fire retardant/low smoke producing cables should be used. Cables with polyvinyl chloride (PVC) insulation or jackets should not be used.**
- **All power and distribution circuits should be routed in raceways or conduit. Nonmetallic conduit should not be used. All cables should be rated for use in air plenums and tested in accordance with NFPA 262, *"Standard Method of Test for Fire and Smoke Characteristics of Wires and Cables."***
- **Communications and interconnecting cable and wiring should comply with NFPA 70, Article 725, "Class 1, Class 2 and Class 3 Remote control, Signaling and Power-limited Circuits" and Article 770, "Optical Fiber Cables." All cables should be rated for use in air plenums and be tested in accordance with NFPA 262,** *"Standard Method of Test for Fire and Smoke Characteristics of Wires and Cables"*

Discussion. Electrical and data/communications cables are a category where there is an unfortunate and regrettable inclination to use the cheapest cable available. The insulation on these cables will, if ignited, create toxic smoke. Cable fires in raceways and cable closets can be particularly hard to reach and extinguish.

2.2.3 Vertical cable chases containing exposed cables shall be enclosed by no less than two-hour fire shafts; cables should be protected in conduit and if not in conduit, cables should be plenum rated with the following additional requirements.

- **Unless all cables are in metallic conduit (except where they cross EMP boundaries) vertical cable chases should be monitored, where feasible, by linear heat detection systems and should incorporate automated fire protection in their enclosures.**

Discussion. Vertical cable chases are not only chimneys, they usually contain important power and communications cables essential to the mission. Most cable insulation is plastic covered and will, if burned, generate toxic smoke. Cable plants are frequently a mix of conduit protected cables, exposed unprotected plenum-rated cables, exposed non-plenum-rated cables and abandoned cables. This guideline is unlikely to change that mix except for new construction or for existing smaller cable chases that can be economically reconfigured. It is not economic to reroute or rewire a large cable chase to achieve a 100% conduit protected or plenum-rated cable

plant. Future cables should be conduit protected or plenum rated. If the majority of cables in a cable chase are in metallic conduit, automated fire protection is not required. Abandoned cables shall be removed because if burned, they contribute to the toxic smoke generating fire load.

2.3 SMOKE, HEAT and OTHER DETECTORS

2.3.1 All areas shall be monitored with smoke or heat detectors.

Discussion. The highest priority for dealing with fire and smoke threats in a UGF *is the earliest possible detection and suppression* of an incipient smoke or fire condition *anywhere in the facility*. Another reason is that, if evacuation is possible, the control room needs to alert evacuees to exit routes that are not smoke filled. Heat detectors should be used in areas where some smoke may be part of normal operations, such as a generator room, and where smoke detectors will give false alarms.

The reason for "*the earliest possible detection and suppression*" is that there may be no option to evacuate personnel and purge smoke. If FPEs follow code, there are many spaces, if protected with sprinklers, that would not need smoke detectors and this application of code poorly serves the life safety of UGF occupants. Consider that it is necessary to ingest outside air in order to purge smoke and that under some design threats, it is also necessary to seal the UGF from outside air because it may be lethal or airborne particulates and contaminants would clog filters. Therefore, the priority is to have occupants arrest any internal hazard at the scene at the earliest stage possible. If evacuation is not an option (i.e., during closed-door operations), an incipient fire situation is the beginning of a worst-case life safety issue.

The reason for "*anywhere in the facility*" is two-fold. Sprinklers alone are not adequate protection from a smoldering and smoky incident that may not generate enough heat to activate sprinklers. Smoke rolling down a passageway or escape route will not activate sprinklers even if the ignition source will eventually activate a sprinkler head. Facility operators need to be able to broadcast information on safe escape routes. To minimize casualties they need current information on which exit routes contain potential smoke hazards and if the smoke is moving. Even in day-to-day operations, when evacuation is an option, other troublesome issues arise if a UGF smoke or fire incident cannot be controlled in the incipient stage. If a fire or smoke incident were to establish a foothold in normal day-to-day conditions, community emergency responders may be required to extinguish it and thereby bring unwanted scrutiny that may potentially compromise the mission and characteristics of the UGF.

An unavoidable reality is that UGFs tend to have a lot of dust. Thus, an added O & M expense is the need to conduct maintenance more frequently than normal on the detectors that are most affected by dust. This environmental reality argues for installing detector systems least sensitive to dust. The purpose of this discussion is not to establish exactly what sort of detectors should be installed. There is enough guidance on the preferred detector types and their performance characteristics in various NFPA and other codes. Detectors should be installed throughout the UGF in accordance with NFPA 72, "*National Fire Alarm Code*." The selection of detectors should be based on early warning and minimum false alarms characteristics. Guidance on the appropriate type of detectors for use in electronically dense spaces is found in NFPA 76, "*Standard for the Fire Protection of Telecommunications Facilities*". Very early warning fire

detection (VEWFD) and early warning fire detection (EWFD) detectors may be warranted for mission critical electronically dense spaces. Detectors should be installed in ALL areas, but not just to code which allows for exceptions. Codes allow for areas with a limited amount of combustibles to go without detectors. For example, areas above ceilings and under raised floors are not necessarily required to have detectors. However, these areas can have wiring, light fixtures, convenience outlets, power supplies, HVAC fans, stored combustible supplies, construction debris, dust accumulation, etc. that can cause a lot of smoke, are difficult to reach and are not easily ventilated. A guideline that addresses these spaces is found below.

2.3.2 Detectors shall be installed in all Air Handler return plenums.
Discussion. This backs up the previous guideline to install detectors throughout the UGF. If any individual detector fails to pick up a hazard, or airflow causes the hazard to bypass an individual room detector, the plenum detector will provide the early warning. Plenum detectors are not a substitute for individual space detectors. Some codes do not require room detectors if plenum detectors are installed. Both should be installed under this guideline.

2.3.3 Fire alarm evacuation zones and smoke evacuation zones shall be coordinated with fire zones, HVAC zones and room-flood clean agent zones.
Discussion. In some UGFs built during the Cold War, the HVAC engineer and FPE did not coordinate either their physical plant or terminology. Those Cold War fire and smoke detector zones bore little correlation to fire zones or any other "zone" designation. Systems in those UGFs appear to have been designed by separate individuals who did not talk to each other. For example, we found some larger fire zones that were supplied by two HVAC systems, only one of which shut down in response to a fire alarm in the zone. That same apparent lack of coordination infected terminology. Announcements over a public address system of an alarm in "zone x" sometimes resulted in confusion about whether the alarm was in fire/smoke detector zone x, fire zone x, room-flood clean agent zones x or HVAC zone x. In some cases assessments found that fire and smoke detector zones covered portions of two separate fire zones. Addressable smoke and heat detector technology allows for activated detectors to transmit their location which has the effect of making each detector a virtual fire zone. Detectors can be programmed so that each detector can individually initiate specific tasks such as close dampers, close fire doors, recall elevators and so on. The physical boundaries of a defined fire zone are still needed in accordance with Section 2.1 (Fire Zones) and the other system's layouts and terminology should be coordinated with them.

2.3.4 Remote annunciators or graphic panels should be installed at numerous locations.
Discussion. "Numerous" is left up to the owner and designer. A design with numerous panels is not common practice**;** it raises the cost of the installation, but it provides stronger life safety support than is required by any code. During smoke or fire there are safety considerations about whether the adjacent zones are smoke free, partly or completely filled with smoke. The most user-friendly remote indicator installation was observed in a UGF where a graphic panel was installed on each side of the door between each fire zone. The panels showed the location and alarm status of smoke detectors on the other side. As a minimum, 80 character liquid crystal display (LCD) remote annunciators with alarm acknowledge, alarm silence, and alarm reset functions should be installed at or in close proximity to each UGF entrance. For larger facilities, remote annunciators should be located in areas that are not readily accessible to the main or

alternate fire alarm control system (FACS) panels. For multi-story facilities, remote annunciators should be located in stairwells at each floor landing. This allows the firefighters or occupants to identify which area(s) are in alarm without having to depend on communications with the control room. Graphic panels are the preferred equipment for the remote annunciator function because occupants and rescue personnel that are not thoroughly familiar with the UGF can more quickly grasp the location of hazards and respond.

2.3.5 All Alarm, annunciator and sampling display panels that monitor normally unmanned spaces should be wall-mounted as close to the access or exit door as possible.
Discussion. When display panels for an alarm system are mounted away from the access doors, responders have to cross the space causing the alarm condition in order to read the panel. This same guideline should also apply to electric distribution panels. The objective is to minimize a responder's exposure to a hazardous condition whether it is to determine why a detector alarms or to deenergize a power source.

2.3.6 Detectors should be installed in the false floors and ceilings of all occupied or unoccupied spaces that are larger than about 500ft^2/~46m^2.
Discussion. As stated above, areas above ceilings and under raised floors can have wiring, light fixtures, convenience outlets, power supplies, HVAC fans, stored combustible supplies, construction debris, dust accumulation, etc. that can cause a lot of smoke, are difficult to reach and that are not easily ventilated to remove smoke. Activation of false floor and ceiling detectors in critical spaces should be indicated by a graphic annunciator near the entrance of their space and they should also be identified by high-visibility ceiling or wall-mounted indicators as close as possible to the detectors. These two features allow any responder to act more quickly than if the responder had to guess which floor panels to lift, call the Control Room for information or leave the space to find that information elsewhere.

2.3.7 Detectors should be installed in normally unoccupied spaces.
Discussion. As described earlier, smoke purge may not be an option in closed-door operations. It also bears reiteration that sprinklers do not activate on smoke and may not activate in response to a smoldering incident or before the source of propagating and billowing smoke is suppressed. To contain a smoke incident at the earliest possible opportunity and to enhance life safety it is necessary to monitor spaces that traditionally only receive sprinkler protection. Monitor the entire length of escape routes, including stairwells so that the safety or hazards along each route can be monitored and announced to evacuees if necessary.

2.3.8 Detectors tested in spaces with obstructed ceilings should be tested as a system.
Discussion. This guideline diverges from NFPA 72, *"National Fire Alarm Code"* which generally only requires individual detectors to be tested in accordance with the manufacturer's instructions. However, that detector test is limited in that 1) it only verifies that if detectable smoke enters a detector, the detector will alarm and 2) it does not verify that a detector installation will alarm at the earliest development of detectable smoke. In more than one UGF, there have been smoke incidences that progressed to dense smoke before occupants visibly detected the condition. The installed, but operating smoke detectors were bypassed by the air dynamics in the rooms. Subsequent tests using smoke generators that were moved around the rooms revealed the deficiencies of relying on individual smoke detector tests as a substitute for a

system test. Spaces whose ceilings have projections, ducts, pipes, structures and so on could prevent early detection of smoke by the inappropriate placement of the individual detectors. Mission and support system modifications made years after the facility is put into service can have the same effect. To ensure that smoke will not layer or bypass the detectors and prevent early activation, spaces with obstructed ceilings (which are defined in NFPA 72, *"National Fire Alarm Code"*) should also be tested with a smoke generator in addition to demonstrating the performance of individual detectors. This generally means most of mechanical spaces, but no spaces with flat ceilings, e.g., those with suspended ceiling tiles. Testing whole rooms with a smoke generator adds cost to the testing program. The smoke generator should be positioned to generate smoke near likely locations of equipment that could overheat or near other potential sources of fire. The HVAC system should be operated in normal day-to-day mode during this test. This system test can also be combined with an acceptance test of the smoke removal system. When space modifications are made that add or remove walls, large pipes or ducts or change other obstructions that can alter smoke flow, the space should again be tested as discussed above.

2.3.9 EMP protected detectors should be installed if EMP is a design threat.
Discussion. If the UGF has an EMP protection criteria, the entire detection and fire alarm control system should be EMP protected. See Section 2.10 (EMP Protection) for design guidance.

2.4 FIRE ALARM CONTROL SYSTEMS (FACS)

The concern is survivability of the FACS function. The primary FACS panel (also called the Fire Alarms Control Panel (FACP)) shall be located at a constantly attended location where its indications and alarms are displayed and can be monitored 24/7. This location serves as the Fire Command Center as described in NFPA 520, "*Standard on Subterranean Spaces*".

FACSs installed in many Cold War UGFs consisted primarily of a FACP connected to a system of smoke/heat detectors and alarm devices. Modern FACS also signal the HVAC system to automatically close fire/smoke dampers, close fire doors and realign the HVAC to control migration of smoke and to conduct smoke evacuation. See Section 2.13 (Smoke Control) for additional discussion of smoke control functions. In more complex FACSs, automated functions require logic connections between the FACP and the Supervisory, Control and Data Acquisition (SCADA) system (or the Building Automation System (BAS)). FACS Operations and Maintenance requires site-specific and sometimes proprietary software. The software usually requires a vendor to not only design and test the initial software (typically on site), but the vendor to return each time the software needs to be upgraded. If the software crashes during closed-door operations it creates problems which are discussed in Section 2.15 (Manuals and Drawings).

2.4.1 An alternate master FACS panel should be located in a different fire zone than the primary master panel.
Discussion. The primary control room location is also subject to fire and smoke hazards whether the hazard source is the control room or spaces adjacent to it. If it has to be evacuated, there

needs to be an alternate location where the master FACS panel monitor and control functions can continue in a separate fire zone rather than in the fire zone that contains the primary control room. The alternate master FACS also serves as a backup in the event that the server in the primary master panel crashes and cannot be restored. If possible, the preferable location for the alternate master FACS panel is in a fire zone designated as a safe refuge. This location becomes the alternate Fire Command Center.

2.4.2 The alternate master FACS panel should not be slaved from the primary.
Discussion. If the alternate panel is slaved to the primary master FACS panel, both of them can be lost to the same damaging event. The utility of the alternate to backup the primary is lost if the alternate is slaved to the primary. Separating the data lines of the alternate from the primary is more expensive than a slaved installation, but it will provide the occupants with life safety information in the event that they cannot reach and monitor the primary panel or it crashes and becomes inoperable. This issue is further discussed in Section 2.15 (Manuals and Drawings).

2.4.3 An EMP protected FACS shall be installed if EMP is a design threat.
Discussion. If the UGF has EMP protection criteria, the entire detection and FACS should be EMP protected. See Section 2.10 (EMP Protection) for design guidance.

2.4.3. A capability should be installed to alert off-site authorities to hazardous UGF conditions if the UGF does not have an on-site 24/7 professional firefighting staff on-site.
Discussion. If a UGF has only a few people in it during its least populated operating condition (e.g., middle of the night in normal day-to-day operations) it is possible that the occupants could be overcome by smoke, carbon monoxide, contaminated food shared by all, a rapidly transmitted incapacitating pathogen or any other hazardous event. It would enhance life safety if FACS alarms that were not silenced by the UGF staff would, after a suitable time delay, alarm at some responsive 24/7 staffed entity outside of the UGF. Persistent, unanswered alarms on the FACS and the atmospheric control monitoring panel are examples of alarms that should alert monitors away from the UGF to initiate actions to investigate the health of the UGF crew.

2.5 FIRE SUPPRESSION

These guidelines are based on a strong three-tiered fire suppression system for critical mission spaces, to wit;

- extensive supply of hand-held fire extinguishers,
- room-flood clean agent systems for critical electrical and electronic equipment and
- water sprinklers throughout that are supplied by multiple water sources where possible.

A three-tiered system is a deliberately staged set of fire suppression equipment focused on stopping an incipient fire at the lowest possible level of fire suppression. No longer in critical mission spaces is it acceptable to install ABC fire extinguishers (i.e., suitable for class A (wood, paper, fabrics), class B (flammable liquids) and class C (electrical) fires) and it is not prudent to install extinguishers in these spaces as far apart as every 75 feet (~23 meters). In critical mission electronic spaces it should no longer be discretionary to install clean agent room flood systems unless there is a documented opt-out exception approved by the mission commander. Variations on a theme of these tiers should apply depending on size, location, and criticality of the

equipment and space being protected. The three-tiered system maximizes the number of fire extinguishers in order to minimize mission disruption from sprinkler water damage.

2.5.1 A large number of widely distributed, high capacity, single type clean-agent hand held fire extinguishers shall be installed throughout critical operating spaces.
Discussion. "Large number" means roughly double the number required by NFPA code. Stopping an incipient fire or smoldering event in its tracks is the basis for this guideline. It is not desired for an incipient fire to progress to the point of needing room-flood systems or sprinklers to control it or to water-log critical mission equipment. The majority of contemporary office and mission spaces in UGFs are largely composed of digital work stations. The cheap, popular ABC dry powder extinguishers are no longer the preferred suppression agent for electronically dense spaces. The specific clean agent used is at the choice of the program manager and the AHJ. Clean agents that cause minimum harm to hot electronics are most desirable.

All extinguishers should be of no less capacity than about 10 lbs. (~4.5 kg) of clean agent each. No ABC dry powder extinguishers should be in or near (i.e., "near" means hallways and corridors immediately outside of) electrical or electronically dense work areas in order to prevent their inadvertent use on electronics. This concern is not to preclude ABC dry powder extinguishers in appropriate UGF spaces such as sleeping quarters; they just should not be near electronically dense spaces. This includes control, telecommunications, computer, data processing rooms as well as operations centers, electrical switchgear and Uninterruptible Power Supply (UPS) rooms. Dry powder extinguishers are commonly found in electronically dense spaces in spite of NFPA 76, "*Standard for the Fire Protection of Telecommunications Facilities*" Paragraph 8.6.3.1.3 that specifically prohibits dry chemical and corrosive liquid agent portable fire extinguishers in signal-processing areas, main distribution frame areas and power areas.

In addition to the caution about the use of ABC dry power extinguishers, CO2 fire extinguishers should not be stocked in UGFs. The reason is the need to minimize the buildup of CO2 during closed-door operations and to forestall a need to use emergency CO2 removal equipment. Endurance calculations incorporate the free volume of breathable air in a UGF and the discharge of a CO2 extinguisher could reduce the expected and planned endurance.

2.5.2 The maximum travel distance to a fire extinguisher in UGF critical mission and support systems spaces should be no more than about 50 feet (~15 meters).
Discussion. Nominally, if a fire fighting policy it written, responders are instructed to use two fire extinguishers and if those two extinguishers do not suppress the fire, to abandon the space and let the automated suppression systems fight the fire. NFPA 10, "*Standard for Portable Fire Extinguishers*" specifies a maximum travel distance to an extinguisher of 75 feet (~23 meters) and FPEs typically use this criteria, not as the maximum, but as an ordinary design goal. This NFPA criteria is inadequate for a C4I UGF. In a C4I UGFs, preservation of the mission drives the first response. Therefore, responders should not have to travel more than about 50 feet (~15 meters) in any direction from an incipient fire or smoke incident to find not only the first fire extinguisher, but the second one. It takes no less than 20-25 seconds for a person to travel a 50 foot (~15 meters) unobstructed straight line and back to get a fire extinguisher and about 45-55 seconds for 75 feet (~23 meters) and back. Typically, critical electronic spaces in UGFs are densely packed with obstructing electronic and electrical equipment, so in many cases 50 feet

(~15 meters) means going around cabinets, racks of equipment and other obstructions that delay application of the fire extinguisher in the first instance. This is why this guideline specifies “about”, it depends on the obstructions and the fact that UGFs are rarely laid out in neat linear dimensions. The goal is to keep the round trip to less than 30 seconds. In normally occupied spaces, extinguishers should be provided in the spaces. Along corridors in occupied areas of the UGF one extinguisher should be provided at every 50 linear feet (~15 linear meters). This allows occupants in small rooms an opportunity to quickly find a fire extinguisher outside their spaces. Along access corridors, roadways and tunnels that are primarily for transit between the entrances and the occupied spaces, the spacing of fire extinguishers can be relaxed to NFPA standards. The key point about fire extinguishers in UGFs is that in general, more is better. The exception is in small spaces where the discharge of two clean agent extinguishers would exceed the safe concentration of the agent, i.e., the concentration should not exceed the Lowest Observed Adverse Effect Level (LOAEL). In such spaces, it may be better to have the responder find the nearest extinguisher just outside the door to the space.

Note: This guideline to space fire extinguishers no more than 50 feet (~15 meters) apart should be coordinated with hose cabinet spacing. In Section 2.6 (Fire Pumps, Fire Mains and Water Supplies) we will recommend that hose cabinet (with fire extinguisher) be spaced every 100 feet (~30 meters)**.** The intent is to alternate fire extinguishers between hose stations so that there is a fire extinguisher every 50 feet (~15 meters) whether it is in an extinguisher cabinet or in a hose cabinet. This recommended arrangement will approximately double the number of extinguishers compared to the recommended spacing found in NFPA 10, *“Standard for Portable Fire Extinguishers”.* The extinguisher costs will obviously double and extinguisher maintenance and testing costs will also increase.

2.5.3 Room-flood clean agent systems with back-up (i.e., reserve) bottles shall protect critical electronic and support system spaces.

Discussion. The reason for this guideline is mission survivability. We favor the following catch-phrase or motto as emblematic of our approach for protecting critical electronic spaces: **“*Fire protection in mission critical spaces is not designed properly if a fire progresses to the point of needing sprinklers for suppression.”***

Room-flood clean agent systems DO NOT replace sprinklers; they complement the sprinklers that MUST be installed throughout the UGF to support life safety and structure. The specific type of room-flood clean agent system is up to the program manager and the AHJ. NFPA 75, "*Standard for the Protection of Information Technology Equipment*" provides guidance on how to protect these sensitive equipment rooms. In general, the code position on installation of room-flood clean agent systems is that installation is at the facility owner’s discretion. The UFC defers to NFPA 75 on this matter. For Special Purpose Underground Structures, it is a significant cost-benefit advantage to install room-flood clean agent system. Suffice it to say that the electronics and electrical systems in C4I UGFs are of critical enough national security importance that they could justify the use of almost any clean agent system available. Invariably, communications, data centers, network control and technical control rooms, sometimes called “Tech Control Facilities” (TCFs) are in this category. Unless there is an equally ready hot back-up for these critical functions at a separate location, it is unjustified for sprinklers (including preaction systems) to be the only automated fire protection for them. There are several compelling reasons

for this position. For example, most racks of electronic equipment cost six figures with some racks as expensive as seven figures (whether their cost is measured in dollars or Euros). The cost of a room-flood clean agent system is typically in the noise compared to the cost of replacing several racks of damaged equipment. Another reason is that if sprinklers are the only automated suppression system, then critical electronics that are not otherwise damaged by a fire incident, but under the sprinkler pattern will be water logged. The quality of sprinkler water is highly variable, i.e., its conductivity, contamination from construction residue and corrosion products depend on its source and regular flushings. The sprinkled equipment may still be functional when dried out. But, all water soaked equipment has to first be tested throughout its entire range of operating parameters and encryption/decryption equipment will have to be recertified before it can be returned to service. All this testing takes time and eliminates the affected functions until the equipment is recertified. Considering the spray pattern of a single sprinkler head (around 100-160 ft^2/~9-15m^2 with the larger area being the most common), a good deal of electronic equipment could be unavailable for days to weeks. For some of that equipment, manufacturer's representatives and specialized equipment are needed to conduct the tests and recertify the equipment's reliability. Those representatives are unlikely to be admitted to the UGF during closed-door operations when testing and recertification are most needed. Most of these undesirable sprinkler effects on the mission can be eliminated if a room-flood clean agent system activates before the sprinklers activate.

Network centric architecture will not replace the end-user TCFs which are particularly costly. While network centric technology may eventually reduce the volume devoted to TCF functions, it is not expected to eliminate TCFs in the foreseeable future. The cost of a redundant and operational critical electronics capability elsewhere (recommended by some FPEs) can be several orders of magnitude greater than the cost of any room-flood clean agent system available.

Where multiple room-flood clean agent systems are to be installed in a given UGF, it is preferred to make all of them the same agent in order to reduce maintenance complexities. All room-flood clean agent systems should be installed with both primary and back-up (i.e., reserve) agent cylinders in place at each clean agent location, piped and ready for immediate use. Clean agent cylinders, even though they may be the same size are not interchangeable from one location in a UGF to another. That is because each cylinder is charged with a calculated weight of agent to deliver the proper concentration for the volume of the specific space being protected.

2.5.4 Room-flood clean agent tanks should be installed outside the space they protect.
Discussion. This protects the clean agent bottles and electronic or mechanical activating equipment from any hazards in the space. It allows operators direct access to the releasing mechanism without going into the protected space.

2.5.5 Room-flood clean agent releasing mechanisms shall be installed outside the space they protect.
Discussion. Guideline 2.5.4 does not require the agent tanks to be installed outside the space although that is the preferred location. Where clean agent tanks are installed inside the space they protect, e.g., when outside space is limited, an electrical manual release shall be mounted inside by each exit door and a mechanical/pneumatic manual release shall be mounted outside

close by an exit door. Therefore, no matter where the tanks are installed, a releasing mechanism shall always be accessible outside the protected space.

2.5.6 All penetrations through room-flood zones shall be sealed with fire stop, with the following additional requirements.

- **Automated fire-rated smoke dampers that can be easily reached (and manually operated if necessary) should be installed in ventilation penetrations.**
- **Signage cautioning against unauthorized penetration of the clean-agent protected zone shall be prominently posted on all interior and exterior zone boundaries including walls, ceilings and floors.**

Discussion. Many operators and some program managers do not comprehend that room-flood clean agent systems, as well as some water mist systems that are propelled by a tank of high pressure nitrogen or air, are "one-shot deals". They question the restrictions that prevent them from their inclination to penetrate boundaries, ad hoc to install new cable runs and other equipment. That is, they do not comprehend that if the clean agent does not extinguish the fire, there is no second shot. Clean agents discharge very rapidly (in seconds) and once only; there is no continuous agent supply as there is with water sprinklers. In any event, there is a requirement that the boundaries of the room where room-flood clean agent systems are installed remain particularly well sealed. This includes physical sealing of all penetrations such as pipes and wires and fire-rated dampers for the HVAC system. Otherwise, the agent leaks out and is ineffective. Thus, the signage requirement for clean agent zone boundaries is “shall” versus the “should” required for ordinary fire zone boundaries. Installation of easily reached manually operable dampers is a damage control issue. It permits operators to quickly and physically force dampers closed if their pneumatic or electric actuation systems are inoperable. The previous paragraph urges the installation of back-up supplies of clean agent. A back-up allows for replacement protection during a closed-door operation if the primary cylinder was used. Or, in case the first "shot" was not effectively contained in the space, there may be an opportunity to correct the leakage and get in the second "shot" before the sprinklers activate. If these same zones are also EMP protected, the fire boundaries must be coordinated with the EMP protection designer to ensure that wave guides beyond cutoff (WBC) which penetrate the clean agent zone boundaries can be properly sealed (e.g., with fire stop or fire/smoke dampers) to contain the clean agent.

2.5.7 Clean agent protected spaces should be identified by distinctive terminology.

Discussion. Another issue related to room-flood clean agent systems is their designation as "zones". A room-flood clean agent protected space could be a sub zone within a fire zone or there may be more than one such protected space within a single fire zone. The term "zone" for a fire zone is the senior use of the term "zone". Once the term "zone" for a room-flood clean agent protected space appears on the early A & E drawings, it tends to get engraved on all room and clean agent system placards as well as FACS panels and control room mimic boards and software. Design engineers should terminate this practice. Rename room-flood clean agent protected spaces as "FM-200 Area 1" or Halon Space 1" or "lnergen Cell 1" or "Argonite Vault 1" or use any other appropriate synonym. Operationally, what we would like to avoid is a public address announcement of an "alarm in zone x" during closed-door conditions where uninitiated occupants that are fully engaged in mission emergencies get unnecessarily confused and distracted.

2.5.8 Automatic sprinklers protected from design threats shall be installed in all UGF spaces.

Discussion. All codes require sprinkler installation. This guideline adds some unique design cautions for installing sprinklers in UGFs. The next guideline discusses where the use of pre-action sprinklers may be more appropriate than wet-pipe sprinklers. This guideline also discusses why sprinkler designers need to understand the mission and the threat context in which the sprinkler systems must operate in UGFs because they are different than anywhere else. Typically, sprinklers are the only suppression system required when preserving mission capabilities is not a priority and the design threat is primarily earthquake-induced seismic shock. As discussed on the first page, when life safety is not at immediate risk the first fire protection priority in C4I UGFs is to preserve its mission capability. Sprinklers must operate reliably, in spite of damage when the fire situation deteriorates and threatens lives or when the mission capability can no longer be preserved. The threat context in which the sprinklers must survive to operate reliably is when seismic shock or ground motion has occurred, e.g., not just an earthquake induced shock, but shock and ground motion induced by the effects of very large conventional explosions or nuclear weapons effects which can rupture sprinkler or fire main lines. The threat to sprinkler systems is not just shock induced motion, but falling rock and concrete. Sprinkler systems contain significant water pressures distributed throughout the UGF. Thus, sprinkler system response to WMD induced ground shock, which is untested and unknown for the worst-case scenario of a closed-door operation, could produce damage to the sprinkler system and jeopardize critical operations in a time of severe operational stress. See Section 2.6 (Fire Pumps, Fire Mains and Water Supplies) and Section 2.9 (Ground Shock Protection) for supporting discussions.

The UFC, NFPA codes and many other codes almost universally require installation of sprinklers in all new construction and this also applies to UGFs. What those codes do not deal with is sprinkler system designs to cope with the threat environment to which UGFs may be subjected. This is why significant safety margins to insulate sprinklers and fire mains from the damaging effects of physical shock and differential motion are specified in a following guideline. Even when a threat environment is not part of the design requirements, C4I facility managers and operators (above or below ground) resist the installation of wet-pipe sprinklers as the only fire suppression agent in their high value electronic and electrical spaces. This is because there is a small probability that sprinkler heads and connectors may be accidentally broken or they will leak and disrupt or destroy the electronics needed for the UGF's mission.

Sprinklers have an additional unfortunate reputation in C4I facilities because operators perceive that sprinklers are typically allowed by firefighters to continue discharging too long after a fire is out. This results in unnecessary water damage to equipment that is otherwise undamaged by fire and smoke. The time to accomplish the ensuing clean-up and recovery are also viewed as drawbacks. The understandable approach of FPEs and firefighters is to get the fire out; clean-up is someone else's problem. This is also why many sprinkled facilities do not have drainage systems in electronic and electrical spaces. Sprinkler water drainage is not the FPE's responsibility. The consequences of sprinkler activation fall most heavily on the facility operators. Recovery efforts can be significantly delayed while facility and mission operators vacuum standing water, dry out their spaces, restart, test and, if necessary recertify their equipment. Firefighters, FPEs and AHJs rarely get involved in this part of the problem. When

mission continuity is at stake and protected in an expensive UGF, common sprinkler design practices are no longer annoyances, they are unacceptable to many operators. Since the first responsibility of fire protection is to preserve life and structure, FPEs encountered in almost all UGF design actions have been generally and understandably oblivious to, uncomprehending of or disdainful of the consequences of sprinkler accidents on missions.

While the risk of leakage or accidental sprinkler head breakage in normal day-to-day operations is generally very small, these risks are considered by most electricians, communications, data systems and network control operators to be too high if their electronics or electrical systems are critical to the mission. That some FPEs dismiss these concerns has resulted in sprinkler water valves being shut in instances of operator rebellion. It would be prudent to design sprinkler systems to accommodate operator concerns rather that to override them. The next two guidelines would maintain the necessary code mandated fire protection sprinkler performance and ameliorate operator wariness about sprinkler vulnerability and reliability.

2.5.9 Pre-action sprinklers shall be installed in critical electronic spaces.
Discussion. The "shall" instead of "should" is intended to give priority to operator concerns while maintaining the ultimate objective of saving lives and the structure. "…shall be installed…" is especially important in critical electronic spaces where room-flood clean agent systems have not yet been installed. The cost of a pre-action valve station is considerably below the cost of a typical rack of electronic equipment. Pre-action sprinklers provide critical mission equipment a margin of safety from sprinkler and connector leaks as well as the difficult to predict attack damage effects on the sprinkler system. Pre-action sprinklers also allow room-flood clean agent systems to activate first as part of the three-tiered fire protection approach. Installing pre-action sprinkler systems and cross-zoned detectors to reduce the chance of leaks and accidental trips has been one way to mitigate operator anxiety and provide fire protection that is mission sensitive. Emerging concerns for the deleterious effects of Microbiologically Influenced Corrosion (MIC) in sprinkler lines (including pre-action systems) tends to undermine operator confidence in the reliability of any sprinklers over critical electronics. Pre-action sprinkler systems should be pitched to permit complete draining after any wet operation. Pitching pre-action sprinkler systems has not been common practice even though NFPA 76 "*Standard for the Fire Protection of Telecommunications Facilities*" requires it. Installing pre-action systems so that they can be drained or blown dry after any test or operation will reduce the incidence of MIC and surprise leaks. Schedule 40 cut groove pipe should be used instead of rolled grooves.

2.5.10 Survivable and damage-tolerant sprinkler systems should include the following features:

- **Isolation valves for all sprinkler systems shall be easily accessible and operable.**
- **Additional isolation valves should be installed in fire mains if the zone they protect is separated by a floor or in a different building from the central fire main manifold.**
- **Isolation valves shall be clearly and uniquely identifiable to the uninitiated.**
- **Mimic placards shall be mounted close by or on isolation valves to identify what spaces and sprinkler lines are served by the valve.**
- **Pendant or upright sprinkler heads (except deluge heads) should be protected by wire cages at locations where human activity could easily hit the head or the head is close to a hard surface that could move in response to seismic or ground shock.**

- **Sprinkler heads in drop ceilings should be recessed.**
- **Sprinkler heads shall be no closer to a hard surface or structural component than 200% of the ground motion imposed by the design threat.**
- **Sprinkler lines shall be shock isolated to tolerate 200% of the design seismic or ground shock.**

Discussion. These additional sprinkler system guidelines protect, with margins of safety, against the many ground shock uncertainties that accompany blast and WMD effects. Those margins of safety are needed because there are always uncertainties in the propagation of blast and WMD effects, the response of individual rock and concrete structures and the myriad connectors in a modern sprinkler system. The reason for a greater number of isolation valves than normal design requirements is to isolate damaged sprinkler piping to the smallest zone possible while repairs are underway. Guidelines for installing additional isolation valves to improve damage tolerance are discussed in Section 2.6 (Fire pumps, Fire Mains and Water Supplies). A UGF design team, i.e., the structural and FPE, should separately calculate the requirements for earthquake seismic protection and protection from ground shock induced by the design threat; then provide the hanger, bracing and flexible coupling design that protects against the greatest impulse. A common misconception held by A & E firms and FPE is that earthquake seismic shock is similar to ground motion shock from large explosions and they are not; their impulse loadings on piping systems are not the same. A FPE is unlikely to know how to calculate for ground shock which is why he needs to work with a structural engineer.

Sprinkler heads are exposed to a host of potential perils that can cause unexpected discharge. In mechanical, electrical and electronic spaces they can be installed quite close to the top of cabinets and equipment where operators frequently store spare parts or equipment destined for the next upgrade. Inexpensive protection from unintended contact is to use wire cages over sprinkler heads. Another sprinkler head concern is when they are installed too close to features that can impact them during ground motion. NFPA 13, *"Installation of Sprinkler Systems"* specifies clearances from obstructions and surfaces such as ceilings and walls. Sprinkler heads should add 200% of the calculated ground motion distance to the applicable NFPA 13 specified clearances. Here, the term "sprinkler heads" is interpreted to mean either the bare head itself or the wire cage; whichever is closest to the hard surface or structural component. While hard surface is self-explanatory, structural components in UGFs have a special interpretation not found in the codes. Here, the term "structural components" means any tock or concrete reinforcement or containment system such as rock bolts, chain link or fencing fabric or any other system or components designed to catch fallen rock or concrete

2.5.11 Flexible couplings should be installed where piping may experience asymmetric motion.

Discussion. This guideline applies primarily where fire protection piping (defined as fire mains, sprinkler lines and pneumatic air lines where used to operate dampers) cross between a shock isolated area to a non-shock isolated area. It is particularly important if the piping is anchored in both areas. It also applies at sharp piping turns (30^0, 45^0, 60^0 and 90^0 elbows) in non-shock isolated areas. Flexible couplings dampen destructive effects on fire protection piping when different structural areas move in different directions from ground shock.

2.5.12 Pneumatic air line should be welded steel and not soldered or brazed copper.
Discussion. Room fire temperatures melt solder and brazed copper connectors which can result in a steady stream of pressurized fresh air feeding a fire in an otherwise isolated space. Compare typical room temperatures during a fire **(**~ 1750^{0}F or 950^{0}C) to the melting temperature of various solder and brazing media and the problem becomes obvious. The range of melting temperatures for typical tin-lead (Sn-Pb) solder alloys is around 300^0-420^{0}F **(**182^0-215^{0}C); Pb-free solder melts around 480^{0}F (250^{0}C). While brazed copper is the common practice for pneumatic air lines, the melting temperature of various silver-copper (Ag-Cu) alloys is still below, but closer to room fire temperatures and there is a risk that they too can melt. Brazing alloys melt around 1435^0-1635^{0}F **(**780^0-890^{0}C); the higher the silver content, the higher the melting temperature and brazing cost. Pneumatic controls engineers and FPEs need to understand this risk and coordinate their efforts to install pneumatic air distribution lines that are not vulnerable to ordinary fire temperatures.

2.6 FIRE PUMPS, FIRE MAINS and WATER SUPPLIES

2.6.1 Multiple fire pumps should be separated by as much physical distance as possible.
Discussion. This is to prevent loss of all the fire pumps to a single localized industrial accident or attack damage. Thus, fire pumps or their controllers should not be collocated, i.e., should not be right next to each other. Where possible, each fire pump and its power supply should be in separate fire zones. If that is not possible, fire pumps should be separated by no less that about 15 feet; the diameter of a sprinkler discharge pattern. Each fire pump should have its own driver with independent power supplies (whose main breakers are in separate rooms) and controls meeting the requirements of NFPA 20, "*Installation of Centrifugal Fire Pumps*".

2.6.2 Fire pumps and controllers should be rated to operate in moist and dusty environments.
Discussion. Most fire pump installations have two or more pumps. Together with their controllers they are always located close together. Their physical proximity constitutes a fire protection Single Point Vulnerability (SPV). Any small or localized industrial accident or attack damage near the pumps could destroy the entire fire pump installation and the UGF’s ability to use its sprinklers and hoses. Thus, the previous guideline’s recommendation to separate multiple fire pumps. Fire pump motors are frequently built to Open Drip Proof (ODP) specification meaning they are designed so dripping water cannot enter the motor. If a fire pump or its controller is not weather-proof, then activated sprinklers near their vicinity could wet them causing them to short and drop off line. This is a concern even if pumps have been separated. In the worst case operating condition, fire main pressure may only be provided by the UGF’s fire pumps and thus, an extra layer of relatively inexpensive pump protection is recommended by specifying weather-proof equipment, whether the pumps and controllers are separated or not. Fire pump motor enclosure specifications should require TEFC (Totally Enclosed Fan Cooled) or equivalent and controller specifications should require NEMA (National Electric Manufacturers Association) Type 3R, i.e., raintight and weatherproof or equivalent.

2.6.3 At least one pump should be powered by non-electrical means, preferably directly driven by its own diesel engine.

Discussion. This is not a substitute to replace fire pumps powered from emergency generators per NFPA 70, *"National Electric Code"* Article 700. A non-electrical directly driven fire pump backs-up the emergency (i.e., diesel) generators in case the design threat causes damage to any part of the emergency generators or the electrical distribution system. At least one pump and its control systems should be EMP protected if the threat includes EMP effects. See Section 2.10 (EMP Protection) for design guidance.

2.6.4 A fire main that is connected to a community or external water supply shall have remotely operated isolation valves located internally as close to where the source of water enters the UGF as possible, with the following additional requirements.

- **A fire main that is connected to a community or external water supply shall have isolation valves that are located where the supply line taps the community water main and that can be remotely operated from inside the facility.**
- **The entire fire main shall be shock isolated to tolerate 200% of the design seismic or ground shock load and have flexible couplings where seismic or ground shock loads could stress it asymmetrically.**

Discussion. Fire mains in UGFs are typically supplied either directly from an external water source and/or the external water source feeds an internal water reservoir. This dual arrangement deals with the possibility that threat conditions could sever the connection to the community water source. In some designs, the community water source supplies internal reservoirs and dedicated fire pumps in the UGF then supply the fire main from the reservoirs. Current practice is to supply standpipe and sprinkler systems from a common fire main. Flow capacity of the fire main is designed to supply both applications simultaneously (refer to NFPA 13, "*Installation of Sprinkler Systems*" and NFPA 14, "*Standard for the Installation of Standpipe and Hose Systems*"). A fire main that supplies both applications may be the largest diameter pipe in the UGF that is constantly pressurized (chilled water supply and return lines may also be constantly pressurized). The community or external water supply is essentially an infinite water source compared to the volume of most UGFs. If the fire main is connected to the community water source and it is ruptured inside the facility, uncontrolled flooding could result. Thus, it is important to have remotely or automatically operated isolation valves to quickly isolate the facility from the potentially infinite water supply. These valves must be easily reached for manual operation in the event of control failure. Large explosions cause seismic or ground shock which can result in differential motion and rupture piping systems if they are not adequately shock isolated. As discussed for the sprinkler systems, designers should separately calculate the requirements for earthquake seismic protection and protection from ground shock induced by the design threat; then provide the hanger, bracing and flexible coupling design that protects against the greatest impulse. Because a fire main is generally routed throughout a UGF and it may also be routed through some nominally inaccessible spaces, a ground shock induced rupture could be a serious threat to the mission if it cannot be quickly isolated. The point of the shock isolation and flexible couplings is to prevent the rupture in the first place while quick acting isolation valves are to control and reduce secondary damage. See Section 2.9 (Ground Shock Protection) for additional design guidance.

2.6.5 Water shall be stored internally, or externally in a nearby underground chamber, to support the UFC requirements for a reliable source of combined sprinkler and hose operations.

Discussion. This guideline is different than nominal code requirements. Required fire fighting water demands (i.e., flow rates and supply durations) are discussed and stipulated in various codes and the UFC (Volume 3-600-01, Sections 3-1 through 4-2). Those requirements are written for conditions where water supplies are not expected to be disrupted by hostile attacks. Thus, water supplies from public water services or base installation reservoirs are generally sufficient to meet the requirements of a reliable supply (as mandated in UFC Sections 3-4, "*Quantities of Water Required*" and 3-5 "*Sources of Water Supply*"). However, under a UGF's design threat, these otherwise reliable base or community external water supplies or their distribution systems may be damaged and unavailable. Then, the UGF must rely on internally or on dedicated externally stored water for firefighting. Externally stored water used exclusively for a UGF should be protected to the same design threats as its UGF. Where drainage of accumulated sprinkler and hose water inside a UGF is a problem, the minimum recommended volume of water that should be stored for a small UGF exclusively for the use of fire fighting is half the UFC requirement and only with the approval of the AHJ. This half-volume recommendation depends on the situation, e.g., limitations of internal or external space, facility volume, drainage and accumulated water level if the entire firefighting water supply is pumped into the facility. The amount needs to be calculated on a case-by-case basis and waivers granted based on limiting the amount of internal flooding a UGF can experience if the required reserve water supply is pumped into the facility. Where drainage is an issue, code required water storage can result in enough water which, if used, can flood a UGF to many feet of water. Where sprinkler and fire hose water can easily be drained without flooding the UGF, it should maintain an internal water supply that meets all NFPA and UFC requirements. The following discussion amplifies the recommended guideline for small and large UGFs.

- In small UGFs, fire fighting needs that exceed the amount of stored water shall have priority demands on all internally stored water, including volumes needed for domestic or industrial uses. To make this approach useful, plumbing should be in place, a priori so that fire pumps can be quickly realigned to take direct suction from the internally stored domestic and/or industrial water supplies. Where this plumbing arrangement is installed, precautions must be taken to ensure that potable and non-potable water supplies cannot be inadvertently cross-connected. If they can be cross-connected to the fire pumps during a fire emergency, that connection shall be protected with appropriate isolation valves and back-flow preventers. If a fire emergency results in cross-connection of potable and non-potable water, the potable water supply should be isolated, disinfected and retested before it is used again as a potable water source. In existing small UGFs, (i.e., about 10,000 ft^2/~930m^2 of gross floor area or less), the volume of all internally stored water can, if necessary, be incorporated in the required UFC water supply as long as those water volumes can be made quickly available to the fire pumps and those water volumes are measured at the low water levels that initiate automatic refill of their storage reservoirs. During significant fire protection modifications to these small UGFs, the capacity of internally stored water dedicated for firefighting should be increased to the UFC requirements.

- In large UGFs with multiple water supplies (e.g., internal industrial and domestic water or external community and internal reservoir water) each water supply should be capable of providing 100 % flow and duration capacity to the fire pumps. Fire pumps should be connected to take direct suction from any water supply if the supplies are internal to the UGF. A leak in one supply or its piping should not cause both water supplies to drain. The internal water supply or reservoir should have a minimum capacity to service the required fire main flow rate and duration when the reservoir is at the lowest point that activates the refill cycle.

2.6.6 Fire main coverage throughout should include the following direct and ancillary features:

2.6.6.1 Fire mains should have sufficient pumps installed to provide 100 percent flow with one pump inactive (e.g., three 50% pumps or two 100 % pumps).

Discussion. This is an N+1 approach to ensure system reliability and damage tolerance.

2.6.6.2 Each fire zone shall have its own riser with its own control or isolation valve at the manifold.

Discussion. This enhances damage tolerance by limiting the effects of unexpected damage to sprinkler and hose coverage.

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2.6.6.3 Risers should be interconnected and isolated from each other by control Valves.

Discussion. This is an additional measure to enhance damage tolerance.

2.6.6.4 Fire mains shall not be routed through electrical switchgear or critical electronic spaces.

Discussion. While NFPA 70, *"National Electric Code"* (also abbreviated as the "*NEC*") prohibits water mains in electrical switchgear rooms, this guideline expands that prohibition to critical communications and mission spaces. A leaking or ruptured fire main with 75-125 psi (~5.3-8.8 Kg/cm^2) of water pressure (a typical range for fire main pressures) supplied by high horsepower/high capacity pumps could result in an instant flood and termination of the mission should it occur in critical spaces. For this reason, fire main routing should have priority over ventilation duct and wireway routing in order to meet this guideline. The preferred fire main routing is along corridors or passageways.

2.6.6.5 Where there is no option and a fire main must be routed through electronic or electrical spaces, it should be welded.

Discussion. Fire mains in critical mission spaces pose a leaking joint or rupture threat from ground shock or falling debris. Further, fire main connectors have been known to leak without the stimulus of ground shock or falling debris. In critical spaces with existing mechanically connected pipe, drip pans should be considered. While drip pans will contain a leak, they will not contain a rupture. To protect against ruptures, consider installing breach valves. Breach valves are self-contained and respond automatically to unusually high flow rates by shutting

off water supply to the down-stream piping. This is also discussed in Section 2.9 (Ground Shock). We cannot be entirely sure of how ground shock will affect the fire mains or UGF structure. Space for routing various distribution systems in the overhead is always at a premium. So, once ventilation ducts, wireways and the fire main is in place, it is very difficult to reroute the fire main to an area where, if it is damaged, the damage would pose less of a threat to the mission. This guideline is a precaution to enhance the survivability of the mission from the effects of potential fire main damage.

2.6.6.6 A section of fire main shall be constructed of non-conducting piping, e.g., fiberglass, where the fire main requires dielectric isolation in EMP protected facilities.

Discussion. See Section 2.10 (EMP Protection) for design guidance.

2.6.6.7 Where there is more than one riser or fire main, they should be conspicuously labeled.

Discussion. Risers and fire mains are one of only two pressurized water systems in a UGF. Quick identification and isolation of leaking or damaged fire mains is necessary to limit damage. Conspicuous labels allow anyone to quickly identify and communicate fire main problems to facility operators. Conspicuous labels should include direction of flow arrows and riser or fire main loop number. Each branch line should have at least one label. Labels should be applied about every 20 feet (~6 meters) depending on visibility. In small rooms (i.e., less than 20 feet (~6 meters) in any dimension) there should be at least one label. Except at walls, an observer should be able to see the adjacent labels when standing under one label.

2.6.6.8 Floor drains, sized to remove expected fire fighting and sprinkler water flow, shall be provided in all mission critical spaces.

Discussion. Floor drains have been generally omitted in most UGFs. Yet, if sprinkler water accumulates on floors, e.g., under false floors where power supplies, data lines and other services are located, mission recovery can be significantly delayed. Sprinkler discharge that ends up under false floors requires considerable wet-dry vacuuming to remove. Drains should be installed in all areas based on an evaluation of water damage and consequences to the mission if sprinklers activate. The *"Fire Protection Handbook*", *Chapter 10, Special Structures* recognizes that accumulated water from sprinklers or hoses can be a serious problem in underground structures and that drainage may be required. Where floor designs permit drains, sloped floors leading to sumps should be provided so submersible pumps can be used to remove accumulated water. Where floor drains penetrate EMP protection boundaries, they provide a point of entry for EMP energy fields and currents. These drain(s) shall be EMP protected by a design that takes into account the dielectric constant of the water expected to flow through the pipe. See Section 2.10 (EMP Protection) for design guidance.

2.6.7 Standpipes, fire hoses and applicators shall be provided about every 100 feet (~30 meters) throughout the UGF in accordance with NFPA 14, "*Installation of Standpipes and Hose Systems*".

Discussion. When clean agent and sprinkler systems fail to contain a fire, or a fire occurs in areas not covered effectively by those automated systems, the only recourse is to fight the fire with hoses or abandon the UGF. Installation of sprinklers does not remove the need for standpipes and fire hoses. Fire has a way of confounding and escaping automated systems which are only as good as their programs and designed coverage as well as being susceptible to primary and secondary threat damage. Over time and after a few equipment and space allocation changes, the original automated fire suppression system design coverage is likely to be compromised. If the external environment is lethal, the option for the "in-house" UGF firefighters to back up the automated systems with fire hoses then becomes essential. The recommended spacing complements fire extinguisher spacing recommended in Section 2.5 (Fire Suppression). That is, each hose cabinet should also have a fire extinguisher. NFPA 14, "*Standard for the Installation of Standpipe, private Hydrant, and Hose Systems"* allows hose cabinet spacing of 130 feet (~40 meters), based on 100 feet (~30 meters) of hose plus 30 feet (~9 meters) of water stream. For this guideline, interior manual hose installations should be able to reach any location with two effective hose streams (that is, from two directions where feasible) from a maximum hose run of 100 feet (~30 meters) of 1 1/2 inch (4 cm) woven jacket-lined fire hose. Where a UGF has professional firefighters, the standpipe should have fire department connections, i.e., 2 ½ inch (~ 6.3 cm) connections. Hose runs from adjacent hose stations should overlap by at least 10 feet (~3 meters). Spacing between hose stations should make allowances for runs around equipment and cabinets. The location of hose stations must be coordinated with the designers responsible for laying out potentially obstructing equipment such as HVAC, racks of electronic equipment and so on.

2.6.8 All hose cabinets should also contain a fire extinguisher

Discussion. Cabinets with fire extinguishers are integrated with the UGF fire extinguisher spacing plan, discussed in Section 2.5 (Fire Suppression) to ensure that there is a fire extinguisher about every 50 feet (~15 meters). The contained extinguisher should be the same type and capacity as the stand-alone extinguishers.

2.6.9 Fire hoses shall not be removed from hose cabinets.

Discussion. This guideline is targeted against the practice or removing fire hoses from fire cabinets. That practice may serve some policy in surface buildings, but it can be lethal in an UGF when there is no other option to fight a fire and emergency community services cannot enter to assist.

2.6.10 Fire hoses should be replace about every 10 years.

Discussion. The recommended replacement interval varies depending on the type of hose in the cabinets, their use history and the results of periodic inspections. Depending on the hose material and its lining, dry rot and mildew can destroy the hose. Older hoses made of cotton need to be dried thoroughly after training or testing or else they mildew, smell bad and rot. Many older UGFs retain their old hoses and dry-rotted attack hoses were found fairly often unless a professional fire brigade was part of the staff. The worst time for dry rot to manifest itself is when attacking a fire during closed- door operations. Dry rot hose leaks and delivers an

ineffective hose stream or catastrophically ruptures. While a hose can be replaced by another one, the time it takes to replace the ailing hose can be many minutes, an unaffordable elapsed time to let a fire grow in a UGF. Hoses should be inspected in accordance with NFPA 25, *"Standard for the Installation, Testing, and Maintenance of Water-Based Fire Protection Systems"*.

2.7 SURFACE FIRE HAZARDS

Surface fires threaten UGF operations by preventing access or constraining internal operations. The threat from these fires is from ingesting superheated air, smoke and soot. These threats can force a UGF to shut down operations. A UGF in close proximity to a large external fire load should make contingency plans for shutting down operations if a surface fire results in superheated air, smoke and soot at its air intakes. Wildfires and forest fires are the common external fire threats for UGFs in rural or remote settings. UGFs in urban settings could be threatened by firestorms. Combustible materials around a UGF can ignite from any cause such as natural disasters, (lightening), deliberate attack (arson) or from WMD effects. Sensors at or near the air intakes are needed to inform UGF operators about the condition of the incoming air. External fire loads are concentrated in several sources some of which are not under a UGF's control: e.g., nearby buildings, forests and so on unrelated to the UGF, buildings built over or around a UGF, car-filled parking lots, aircraft facilities, fuel supplies, brush or forests around or on the UGF and so on. The most memorable examples of firestorms were the fires that consumed German and Japanese cities in WWII. During our assessments, one of the more dramatic examples of surface fire hazards with a high potential for becoming a disaster was a large ammunition storage UGF under a mature and dense deciduous forest all of which was surrounded by a 25,000 volt security fence.

2.7.1 UGFs with external support buildings should install an external hydrant system.

Discussion. The water source should be an external source such as a base or local community water supply that community firefighters would use for any other building fire. For remote sites, a base or community water source may not exist and a buried external water supply may be necessary. Fittings and other hydrant accessories should be compatible with those used by the local community firefighters. Water should not be pumped from internal reservoirs to an external hydrant system.

2.7.2 UGFs with brush or forest on its grounds should provide water supplies at strategic locations.

Discussion. Much depends on the location of the fire load, location of the UGF and whether closed-door operations are being conducted. But, above all plenty of water has to be available near the potential fire load. UGFs located on a military base can generally expect the base to have a hydrant system and expect the base fire department to be responsible to control a surface fire under any operating circumstances. For a standalone UGF, away from quick base support, it matters what the operating circumstances are. For day-to-day circumstances, Mutual Aid Agreements with local community firefighters is the option of choice. For remote standalone UGFs where quick response from external response teams is unlikely (such as from volunteer fire departments) the UGF has to plan on doing it themselves or being able to assist any response teams that may eventually arrive to assist. Feasible options to provide water supplies depends

on the terrain and include a buried hydrant system (which is unlikely to be practical in rocky terrain), buried water tanks (with or without pumps) and a dry-pipe hydrant laid on the surface (as long as there is a readily available water supply to connect to). The least expensive option is to lay a dry-pipe to various locations where firefighters can connect hoses throughout the brush or forested areas near where fire trucks can access. In the event of a forest fire, the fire department (dedicated to the UGF or community responders) can connect a hose from the external hydrant or water supply system to the dry-pipe system. This should work well in rocky terrain and where freezing is expected.

2.7.3 Where firestorms or brush/forest fires could be an uncontrolled threat, UGF designs need to take into account how it would operate without a source of outside air for the duration.

Discussion. When wind brings smoke and soot into the air intakes, filters become clogged. When superheated air enters, filters and other exposed equipment may burn and cooling towers cannot function. When fire consumes local power substations, internal power is needed. When all this happens in one extreme event, the UGF may have to shut down. That is, there will be no outside air for breathing or for its cooling towers. The design needs to consider how long the residual air can sustain the occupants compared to how long the firestorm or brush/forest fire could endure. Generator designs needs to consider the specifications for intake air temperature in order for them to remain within their operating envelop. Without operable cooling towers, once-through cooling from a reservoir or something similar needs to be part of the design if, and that is a big if, generators can operate with intake air that is too hot to use for any other purpose. If the design does not make allowance for firestorms or brush/forest fires, the consequences are that the UGF goes cold, dark and quiet until the temperature of the outside air again permits generator and cooling tower operation.

2.7.4 All air intakes should be equipped with heat and particle sensors.

Discussion. In addition to the usual array of NBC sensors, operators need to know the temperature of incoming air as well as its particle content. Heat and particle sensors do not need to be directly in the air intakes, but need to monitor airstreams on their way to various air intakes**;** the further upstream from the air intakes, the better. Tolerable temperature air may be dense with soot particles that would clog filters. While this air may not be suitable for breathing (or cooling towers if cooling tower air is filtered), it may be suitable for running generators. Superheated air is dangerous to most equipment it contacts and generally there are intake air temperature specifications for generators. Operators need reliable and redundant sensors to keep them informed of incoming air quality, particularly during a WMD event.

2.8 SURFACE PENETRATIONS

2.8.1 If external threats can develop superheated gases, heat resistant, remotely operated isolation valves should be installed in both the intake and exhaust ducts as close to the surface as possible.

Discussion. The common WMD design threats can result in superheated air entering a UGF through any surface penetration. An ability to close off those paths is needed. These isolation valves are in addition to passive blast valves which will not close in response to superheated air.

The ability to close off this path with special isolation valves may not be required if active blast valves are installed…depending on the location of the blast valves. Air intake and exhaust penetrations are generally the largest UGF penetrations (after road and personnel accesses). Blocking these openings to prevent outside hazards from reaching any internal equipment is critical to maintain mission and occupant survivability.

2.8.2 Heat, smoke and fuel resistant materials should be installed on exposed blast doors.
Discussion. Burning liquids constitute a threat if they seep in under blast doors. “Exposed” means anywhere in the path of external heat sources. Blast doors are generally not rated as fire doors, but a few fire rated blast doors are available on the market. However, for blast doors that are already installed and that are not fire rated, there are commercially available appliqué materials (e.g., intumescent paints and hot gas seals) that can be added to insulate the doors or to impede the flow of liquids and seal the doors from burning fuels and hot gases. This is also a useful protection if the blast doors are close to the surface and the local terrain can support a significant fire such as a forest fire. The next guideline provides added protection for exposed doors.

2.8.3 Drains should be installed outside exposed blast doors to lead burning liquids away.
Discussion. Burning fuel may accumulate at the doors or leak past protections such as seals. This is a dangerous situation where, with enough burning time; heat on a blast door could warp it or melt the steel rendering the door either useless for its intended function and/or impassable for emergency evacuation. Where drains may be infeasible, consider installing a local and physically protected automated fire suppression system to reduce the possibility that accumulated fuel could burn for any significant time.

2.9 GROUND SHOCK PROTECTION

The purpose of this section is to develop situational awareness about aspects of weapon generated ground shock effects that are not considered in typical engineering curricula. It also provides a more integrated view of ground shock protection techniques than the individual guidelines discussed in each section of this handbook. The effects of WMD weapon generated ground shock are different than the accelerations and displacements caused by earthquakes, i.e.., seismic shock. Fire protection codes generally provide adequate guidance on how to design fire protection systems to survive seismic motions, but they provide little help for dealing with ground shock induced by large explosions or WMD. The primary damage mechanism to fire protection systems for any of these damaging events is ruptured pipes and equipment displaced from their mounts. In simple form, there are three major events that generate ground shock: 1) a large conventional explosion, 2) a nuclear explosion and 3) an earthquake. Because the accelerations and displacements between these major events are different, the FPE must calculate the effects of each and develop a design that will protect against the worst case. The accelerations (i.e., g-forces) from WMD weapons generated ground shock can be orders of magnitude greater than those experienced from seismic shock. The more damaging aspects of ground shock and physical displacement are twofold: falling rock or spalling concrete and asymmetric motion. Bunkers are consistently made with steel reinforced concrete of varying thicknesses, and ground cover including burster slabs. The effects of weapon generated ground

shock and aircraft impact are to displace or spall off chunks of concrete at high velocity that can rupture pipes, crush equipment and cause personnel casualties. Tunnels, however, are excavated in rock and their walls are reinforced by a variety of techniques including concrete liners or various types of rock-bolt systems. While these wall reinforcement techniques have implications for hanger and support systems, the results of tunnel failure from ground shock is much the same as for bunkers, i.e., chunks of concrete liner or rock fall off and can rupture pipes, crush equipment. Asymmetric motion has different effects on structures than simple ground shock. That is, one part of the structure moves in one direction and at the same time another part moves in a different direction. This asymmetric motion can cause pipes that are anchored to different parts of the structure to rupture and cause other unintended consequences.

Shock mounts and hanger supports only provide limited protection from the effects of falling rock or spalling concrete. Several design techniques (as well as operational responses) can improve survivability (i.e., damage tolerance) of fire protection equipment from these effects. 1. Where feasible, equipment such as fire pumps, controllers or FACPs should not be installed directly under rock or concrete. Where installation of this equipment under rock or concrete cannot be avoided or they are already installed under exposed rock and concrete, a specially designed steel structure to protect the equipment from falling rock or concrete should be considered. 2. No matter where located, under rock, concrete or inside a protective structure, redundant equipment such as fire pumps and their controllers should be separated by enough distance so that attack damage, falling debris or an industrial accident cannot damage all of the same type of equipment. This is rarely done, but for UGFs it should be given great priority. Physically separating redundant equipment is an alternative to installing protective structures over equipment. 3. There will be locations where fire mains and sprinkler branch lines cannot be protected from falling debris. The locations of such events are unpredictable and depend on many uncontrollable factors such as the threat's magnitude; it's orientation to the UGF, overburden and geology. Design and operational responses can minimize loss of sprinkler protection under these conditions. The design improvement is to install an adequate number of isolation valves to shut off water to as small an area of damaged pipe possible and to install enough fire hose stations and hose so that all areas of a UGF can be reached by hoses from two directions if possible. The number of isolation valves and hose lengths needed to improve the damage tolerance of exposed fire mains and branch lines will be considerably greater than the typical design based on NFPA or other code criteria. The operational response is to ensure that damage control lockers are stocked with an adequate number and variety of pipe-patch kits that can be used to repair and reconnect damaged sections of the fire main and branch lines.

There are two primary ways to provide protection against equipment displacements caused by ground shock and they affect the installation of all systems including fire protection systems. These are 1) individually shock mount each piece of equipment or 2) globally protect systems by installing equipment on shock mounted pads (also called a raft, bed, platform or floating deck depending on the A & E company's terminology preference). Combinations of each of these are frequently employed which is most common where a shock mounted pad is installed. Shock mounting each piece of equipment is self-explanatory, but the FPE must be aware that vibration isolation and shock isolation are not the same thing. Shock mounted equipment can be used selectively when a UGF uses shock mounted pads for its major equipment spaces, but does not put all fire protection equipment on the pad. A shock mounted pad can be simply a physical pad

on which sensitive mission equipment is mounted or it can be complete buildings. Equipment and systems on shock mounted pads or in shock mounted buildings do not need to be individually shock protected because the pad or building provides the protection. But, flexible couplings are needed where those systems transition between shock protected pads to area that are not shock protected to deal with the asymmetric motion that can be induced by the design threat.

The characteristics of weapon generated ground shock (i.e., from large conventional and nuclear weapons) compared to seismic shock are that the rise time of weapon generated ground shock is much faster than earthquake generated seismic shock and it falls off much more quickly. The characteristics of large non-nuclear explosive impulses are also much quicker to rise and to fall off than for nuclear induced ground shock. Ground motion impulse characteristics of each of the three triggering events are different enough that the fire protection designer should separately calculate the protection requirements for each design threat and provide the hanger, bracing and flexible coupling design that protects against the greatest impulse. To accomplish this, the FPE will need the help of a structural dynamics engineer. The fire protection system design features that should be evaluated against the design threats range from the obvious fire main hanger systems to fire stop used in certain applications.

When the IBC is specified as a guiding code, Section 1604 (General Design Requirements) and Table 1604.5 (Classification of Building and other Structures for Importance Factors) should be used to determine building classification and importance factors for calculating the strength that fire protection systems need to survive seismic or weapon generated dynamic loads. In accordance with Table 1604.5, UGFs should be classified as Category IV buildings and the fire protection systems should be assigned an importance factor (I_E) of 1.5. These are the same classification (Occupancy Category = IV) and importance factor (I=1.5) that would be used from Table 11.5-1 (Importance Factors) of the American Society of Civil Engineers (ASCE) Standard 7-05 (Minimum Design Loads for Buildings and Other Structures) if the ASCE Standard applies instead of the IBC.

2.9.1 Flexible fire stop should be used at fire wall boundaries attached to bunker or tunnel walls.

Discussion. If the design threat can induce ground motion that can rupture nominally rigid fire stop, the joint between a fire wall and a bunker or tunnel wall should be protected with fire stop whose specification can tolerate the induced ground motion. Flexible fire stop is particularly important where the fire wall is anchored to both a ground motion protected pad and the UGF wall. An example would be a shock mounted building in a UGF where it is desired to establish a fire barrier between the building and the UGF wall. In that case, the UGF wall can move a greater distance than the shock protected building whose motion is dampened. The potential result is loss of fire stop integrity if the fire stop is not flexible enough to tolerate the ground motion.

2.9.2 FACS panels installed outside of ground shock protected spaces should be shock mounted.

Discussion. Alarm panels hard mounted to bunker or tunnel walls are at risk of damage and disruption if they are not shock mounted. Shock mounting only mitigates the effects of acceleration and displacement. It does not significantly mitigate the effects of falling concrete or rock. Where that appears a risk, a metal deflector can be installed over the top of FACS panels.

2.9.3 False or raised floor panels should not normally be fixed in place with any type of fastener.

Discussion. Raised and false floors are frequently used in electronic spaces to provide space for cooling air to flow to electronic equipment racks and to route data and power supply lines as well as chilled water lines to room cooling units. Fire protection under a well-designed false floor (in critical electronic spaces) should also include smoke detectors, sprinklers and/or clean agent suppression and moisture detectors. When the design threat can result in ground shock, the type of supports or pedestals on which raised floor panels rest may have to be specially designed to withstand the ground motion. Where ground shock is expected, raised floor designs should be selected on their ability to withstand the ground shock without needing fasteners to fix the floor sections in place. Where ground shock protection unavoidably requires the floor panels to be fixed, additional design features are required that facilitate quick location of an underfloor hazard and the quick removal of the panels that are over the hazard. Identification of the hazard location shall be indicated by a graphic annunciator near the entrance to the space. Under floor detectors shall also be identified by high-visibility ceiling or wall-mounted indicators as close as possible to the detectors. This is a change from a recommended "should" in Section 2.3 (Smoke, Heat and other Detectors) in the guideline for installing detectors in false floors and ceilings to "shall" in this guideline. The reason is that fixed panels, without aides to facilitate quick location and access to a hazard, can cause significant delays in containing it. Tools to quickly remove fixed floor panels (such as cordless drill with bit attached) shall be located at each entrance.

2.9.4 Fire main and sprinkler lines should be shock isolated and constructed to survive ground shock accelerations, displacements and falling debris.

Discussion. This discussion integrates several issues brought up in Section 2.5 (Fire Suppression) and 2.6 (Fire Mains and Water Supplies). It is important to understand the conundrum posed by sprinkler systems installed throughout a UGF. Depending on the scenario, they can be viewed as accidents waiting to happen as well as a means to save lives and structure. That is because sprinkler systems are pressurized throughout a facility (typically from 75 psi to 125 psi (~5.3 to ~8.8 kg/cm^2). The most benign, but never-the-less traumatic scenario is any industrial accident-like leakage or sprinkler activation that results in a significant spray pattern that could disrupt performance of the mission. It is unpredictable where such leakage or accidental activation may occur. This is a particularly sensitive issue in a TCF where many racks of expensive electronic equipment can be water damaged by a single sprinkler head or connector failure. The worst-case scenario results from the variety of fire main and sprinkler failure mechanism that can follow from WMD induced ground shock. The rupture of a fire main or a sprinkler line under this scenario can flood spaces, short out electrical equipment, jeopardize the mission and in some cases, lead to uncontrolled flooding and loss of life. Indeed, UGF sprinkler systems and fire mains, if not designed in the context of the threat, can be more lethal to the mission and occupants than the direct effects of design threats. Therefore, some design

precautions, discussed next, should be taken to militate against such accidents and ground shock induced failures.

2.9.5 Shock isolation hangers and supports shall be used for fire mains and sprinklers hung in areas that are not shock isolated.

Discussion. A consideration unique to installing fire protection systems in UGFs is how to anchor hangers and supports. In a typical ground level building, supports are installed with standard anchors set six or so inches (~15.2 cm) into concrete. However, a UGF may be excavated by different techniques that result in different wall integrity characteristics and this requires different types and lengths of anchors to reliably hold the fire protection systems during a ground shock event. Different types and lengths of anchors may be needed in different locations in a single UGF because different parts of the UGF may have been excavated and reinforced differently. The primary difference occurs between pads and/or buildings that are shock isolated and areas of a UGF that are not. For fire mains and sprinklers installed on shock isolated pads or in buildings, ordinary anchor and hanger techniques are adequate because the pad or building provides ground motion protection. However, when fire mains or sprinklers are hung in UGF areas that are not ground shock protected, the hanger and support anchor design become more demanding and individualized.

In a bunker, the concrete walls and ceilings are constructed relatively uniformly except for thickness and reinforcement. Thus, anchoring mechanisms need to be anchored deep enough to prevent the design ground shock from loosening their grip. Except for specific pads or vaults within a bunker that are designed to be shock isolated, a bunker is expected to respond as a unit to ground motion. Many special purpose underground bunker-type structures do not have shock isolated pads or vaults. Each hanger installed in areas not shock isolated needs to have some spring supports so that the supported fire main or sprinkler line does not move outside the tolerances of its pipe and connectors when constrained by the expected hanger motion.

Hanger designs in a tunnel are a bit more complex. Anchoring a hanger or support on shock isolated pads or in buildings do not need special designs. Hanger and support anchor designs in areas that are not shock isolated depend on how the tunnel was excavated and reinforced as well as the geology and the specific magnitude of ground motion generated by the design threat. A tunnel constructed by the traditional drill and blast technique leaves a significant depth of disturbed rock (typically 12 inches **(**~30.5 cm) that cannot be reliably used to anchor anything. The typical depth needed to reliably anchor a hanger in such a tunnel wall is a minimum of 18 inches (~45.7 cm), i.e., 6 inches (~15.2 cm) beyond the first 12 inches of disturbed rock. Without additional information from the mining engineer, that 12 inch overbreak is only a rule of thumb. The precise anchor depth in each area of tunnel should be coordinated with the mining engineer who has more detailed knowledge of rock strength characteristics and the overbreak damage done by excavation. Excavation conducted by tunnel boring machines or road headers do not leave as much disturbed rock as drill and blast and thus only the first 6 inches is typically considered disturbed. Where this equipment is used to excavate, the typical depth needed to reliably anchor a hanger is a minimum of 12 inches, i.e., 6 inches beyond the first 6 inches of disturbed rock. Again, these are rules of thumb because the geologic features and rock strength

characteristics can vary from one part of a tunnel to another. Coordination with the mining engineer is needed before designing support for areas of uncertain rock strength.

2.9.6 Fire main segments should not be joined by mechanical connectors where the fire main traverses critical mission spaces.

Discussion. There are two considerations with reference to fire mains in critical mission spaces. As discussed in Section 2.6 (Fire Pumps, Fire Mains and Water Supplies), fire mains should not be routed through electrical switchgear or critical electronic spaces. But, if there is no other options than to route a fire main through these spaces, the FPE should be sensitive to the potential risk that every joint in the fire main may pose to the mission. Because of cost, ease of construction and general reliability mechanical connectors are the overwhelmingly preferred method for joining various segments of fire mains and sprinklers. They also have some limited give in the amount of acceleration and ground motion that they can tolerate in order to be useful under a variety of seismically active conditions. But, the FPE should have a firm grasp of what "limited give" means and the distinction between seismic and WMD induced accelerations and ground motion. Those differences have already been discussed. Suffice it to say that mechanical connectors do leak and when fire mains traverse critical mission spaces that cannot afford to be out of commission the FPE designing the system should consider other connection means that are specifically less likely to leak under stress. We are not talking about leaks under industrial accident scenarios, although that is a consideration, but also about leaks induced by ground shock from a WMD attack. Elsewhere in this handbook, it has been pointed out that an entire operating UGF has **NOT** ever been tested to see how it reacts to a design threat and thus, all UGF system designs are based on best engineering judgments, not empirically derived engineering parameters. The best engineering judgment is to minimize the risk of losing mission capability to a fire main rupture or leak. In the absence of data about fire protection system responses to WMD scenarios, that require not only specifically designed shock isolation hangers and supports, but means to eliminate as many possible leakage/rupture points on the fire main as possible. That is why in Section 2.6 (Fire Pumps, Fire Mains and Water Supplies) the FPE is urged to weld any fire main segments that span a critical mission space. Another protective device that is specifically designed to stop high flow rates resulting from a pipe rupture is a breach valve. Breach valves respond automatically and do not require any outside sensor to activate. They will not respond to normal flow rates associated with sprinkler activation. Whether fire main segments are joined by mechanical or welded means we recommend that breach valves be installed at strategic locations to guard against downstream ruptures where the fire main or riser crosses critical mission spaces.

2.9.7 Where fire mains and sprinkler lines can experience asymmetric motion they shall be joined by flexible couplings.

Discussion. Asymmetric motion was introduced at the end of the first paragraph in this section. For fire main and sprinkler line designs in a typical ground level building, this motion is a non-problem except where these systems cross expansion joints. In UGFs, this potential problem is everywhere and liberal use of flexible couplings is generally expected to adequately deal with potential problems. The destructive effects of asymmetric motion are most severe across the boundaries between shock isolated areas and non-shock isolated areas. Anytime a fire main or sprinkler crosses that boundary, it should be protected with a flexible coupling that accommodates the expected ground motion induced displacements. Asymmetric movement

should not occur on a shock isolated pad or building and therefore, ordinary design techniques are adequate. The only exception would be for fire mains that traverse critical mission spaces (discussed in the previous paragraph). In that case, it would be prudent to provide the fire main with flexible couplings just outside of where it enters and leaves the critical mission space in order to provide additional protection from ground motion induced leaks and ruptures.

2.9.8 Where pneumatic lines that operate fire/smoke dampers can experience asymmetric motion they shall be joined with flexible couplings and protected from system loss with an accumulator and a check valve.

Discussion. This guideline is similar to the previous issue about protecting against asymmetric motion in fire mains and sprinklers. The two prime movers for fire/smoke dampers are electrical and pneumatic. The most physically fragile of the two prime movers is the pneumatic system although its apparent advantages are that if properly designed (which is discussed at the end of Section 2.10 (EMP Protections)) it is not subject to EMP disruptions and it puts no demand on the UPS system. For the same reasons that fire mains and sprinklers need flexible couplings, pneumatic systems need them also. In addition, if a pneumatic system loses line pressure or its compressors fail, we do not want to lose the fire protection features. Pneumatic lines to fire/smoke dampers, where they branch from a main pneumatic supply line, should be protected by an accumulator and check valve that can isolate the fire protection portion of the pneumatic system from overall loss of line pressure or compressor failures. Note that additional special precautions that recommend welded steel pneumatic air lines are discussed at the end of Section 2.5 (Fire Suppression).

2.10 EMP PROTECTION

The effects of an electromagnetic pulse (EMP) are not typically considered when designing a fire protection system. In addition, fire protection systems have not been systematically tested to determine their exact response to an EMP, i.e., whether the different components and fire protection subsystems would short, ground or open. The exact disruption mechanism is irrelevant in that the affected system components exposed to an EMP will be disrupted and possibly permanently damaged. Depending on the system failure mechanism, unintended consequences may also occur, such as the release of clean agent fire suppression agent. EMP is the kind of threat that can couple from one conducting system to another and so it takes just one inadequately EMP-protected conduit to put all other systems at risk. In any event, UGF fire protection design engineers and facility operators should expect to lose some or all fire protection system functions if an EMP event occurs and the fire protection systems are not designed specifically to survive that WMD threat.

EMP refers to nuclear or non-nuclear EMP effects. EMP is the burst of electromagnetic radiation from a high energy explosion, particularly a nuclear explosion. However, EMP has been observed from conventional explosions, although at a significantly reduced magnitude compared to a nuclear explosion. EMP can also be caused by a non-nuclear event that causes an instantly fluctuating magnetic field. Lightning also produces an EMP effect, but it is substantially weaker than the nuclear generated EMP effects unless the observer is very close to lightning. The term EMP most commonly refers to a wide area electromagnetic pulse generated by a high altitude nuclear explosion above a 25 mile (~40km) height of burst. It is usually

defined as HEMP. Another nuclear event that causes an EMP is a ground burst nuclear explosion that generates a source region EMP known as SREMP. These events, HEMP and SREMP couple to any exposed conductor, e.g., wires and pipes and induce very high voltages and currents that disrupt or damage unprotected electronic and electrical equipment. Fire protection systems that are not designed with effective EMP protection cannot only be affected in response to an EMP event; they can also be the conduit to damage or disrupt other systems. Each of these EMP phenomena has a somewhat different and complex characteristic. Protection against them requires highly specialized designs and maintenance practices. A more detailed discussion about HEMP and SREMP characteristics that FPEs need to understand for application to special purpose UGFs with an EMP protection design criteria is contained in Appendix A (EMP Effects). Guidance on how to design EMP protection for HEMP is contained in MIL-STD-188-125-1 (DoD, "*HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) PROTECTIONS FOR GROUND BASED C4I FACILITIES PERFORMING CRITICAL, TIME-URGENT MISSIONS PART 1 FIXED FACIITIES"*, MIL-STD-188-125-1 of 17 July 1998. The following describes fire protection systems that could be affected by EMP and what, in general, should be done to protect them.

WARNING: The effectiveness of all EMP protected spaces and systems described in this section should be verified, prior to putting the UGF into service, using the testing protocol provided in Appendix A to MIL-STD-188-125-1. The associated Hardness Maintenance/Hardness Surveillance (HM/HS) procedures should be incorporated into an overall HM/HS plan because the integrity of EMP shielded spaces can deteriorate or be compromised over time. Concurrently, with periodic verification of EMP shield integrity, a fire inspection of EMP shielded space boundaries should also be conducted if the EMP boundary is also a fire zone boundary. Compromises to the EMP protection properties of the boundary frequently result in compromises to the fire protection properties of the boundary. For example, a typical cause is that operators install a new conducting data or communications cable through the boundary (either through an existing WBC or by punching a new and unprotected hole in the shield) and do not use fire stop. That results simultaneously in EMP and fire protection compromises. The first EMP guideline discusses how to design EMP boundary penetrations to meet both EMP and fire protection requirements.

2.10.1 Integrated EMP and fire protected boundaries shall be installed in EMP protected spaces that are also fire zones.

Discussion. Meeting both EMP protection requirements and fire rated boundary protection for an EMP enclosure or vault also designed as a fire zone is a challenge that requires the cooperative attention of the FPE with an EMP engineer. This is because uncoordinated protection design can result in compromises to the counterpart's protection integrity. From a fire protection viewpoint, several features of the EMP protected space requires that cooperative attention, e.g., the steel walls, the RF protective doors, the ventilation ducts where fire/smoke dampers are installed and the WBC through which various pipes and data lines penetrate the steel boundary of the protected space.

Personnel entrances are generally protected by RF protective doors that meet rigid standards. They look nothing like fire doors and they are normally always closed and alarmed to warn when opened. While an EMP protected space may be considered a separate fire zone, the steel walls

of the space and the RF protective doors are generally not fire rated. When an EMP enclosure also doubles as a fire zone, the FPE needs to pay particular attention to how the walls and doors can be upgraded to fire rated status.

If the steel boundary is an entire building in a UGF, there may be no need for additional fire protection of the boundary depending on distance separating the building from any other UGF feature. If the steel boundary is a vault-like enclosure within a building or another space, the steel walls may be clad with gypsum board or a separate fire wall can be erected a short distance from the steel wall. Cladding with gypsum board may not be acceptable depending of access to conduct HM/HS; that is up to the EMP engineer. A separate fire wall provides space between the steel and gypsum walls so that HM/HS of the EMP shield can be conducted. Another solution is to cover the steel with intumescent paint. The selected solution, given constraints of budget and space is a cooperative enterprise between theFPE, the EMP engineer and the AHJ.

RF protective doors (also called EMP doors) are crafted to rigid RF attenuating specifications. Access to the protected space is frequently through two of these doors that are a few feet apart, at the ends of an EMP vestibule, to allow sequential opening and closing. These doors are not normally manufactured as fire door although they are heavy doors that give the impression that they are also fire doors. Without special treatment they are not fire doors. However, a few manufacturers make RF protective doors that are also fire rated. If the installation has EMP doors that are not fire rated, then they may be clad with intumescent paint. The AHJ will need to weigh in on the acceptability of using intumescent paint to gain a fire rating approval.

Other fire protection related penetrations that need EMP protection include ventilation ducts that also need both fire/smoke dampers and a WBC; i.e., both types of protection need to be installed in tandem. Other WBC allow pipes and data lines to cross the EMP boundary while maintaining the EMP integrity. A WBC is generally an open, relatively small diameter array of pipes that do not need fire stop in them if all they do is provide EMP protection. But without fire stop, the boundary does not have fire protection integrity and if the space is protected with a room flood clean agent, the proper concentration of clean agent cannot be maintained. It appears simple enough to fill the WBC with fire stop. However, what most FPEs do not realize is that fire stop materials have varying dielectric properties. So, unless the FPE can provide the EMP engineer with the dielectric properties of the fire stop, the EMP engineer cannot design the diameter and length of the WBC array so that when filled with fire stop, it also maintains EMP integrity. Or, to put it a different way, the EMP engineer does not need to put fire stop in the WBC in order to achieve EMP protection, but the FPE needs the WBC to contain fire stop if the space is to have any fire protection integrity.

2.10.2 An EMP-protected fire alarm control system shall be installed if EMP is a design threat.

Discussion. Copper wire-based alarm systems are vulnerable to an EMP threat if any portion is exposed to the effects of EMP. Copper cables are routinely used to connect detectors to FACS. If the facility has a HEMP or SREMP protection requirement, the fire alarm control system shall be inside the EMP protected enclosure, also called the shielded volume. Any connection from the shielded volume to an external fire alarm control or monitoring system shall be over fiber optic cable (without a metal strengthening member or external sheath) which is routed through a

waveguide beyond cutoff (WBC) pipe which is circumferentially welded to the shield at the penetration point. The diameter of the WBC pipe shall not exceed 4” (~10 cm) and the length of the pipe shall be at least 5 times the pipe diameter. Inside the shielded volume, the connection from the Fire Alarm Control System (FACS) to the sensor heads can be through copper cable. Outside the shielded volume, the susceptibility of smoke detectors that are connected to an external FACS via copper cable is a major uncertainty. There have been reports of fire alarm systems being activated by a power surge from nearby lightning strikes, which are significantly lower in amplitude than the HEMP or SREMP environments.

Pipes and doors have been designed to EMP specifications**;** smoke detectors and FACPs have not. There is no data on how detectors and FACPs will respond to an EMP. Sensors and FACPs that are outside an EMP shield are unlikely to survive an EMP event. For a facility that has sensor heads and FACPs outside the EMP-protected volume, there are two approaches to protecting the transmission from external sensors and FACPs through the EMP to the master FACS inside the shield. The first approach is a copper connection through a specially designed filter/surge arrester combination specifically designed to prevent ground faults and to survive the criteria from MIL-STD-188-125-1 associated with the length of cable run external to the shielded volume. This filter/surge arrester can also be designed so that it will not interfere with the functionality of the external sensors or FACP. The effectiveness of the filter/surge arrester must be checked periodically. A second approach is to use fiber-optic connection from the external FACP to a master FACS inside the EMP-protected volume through a WBC. In both cases, the devices outside the EMP-protected volume are not protected. They should be considered expendable, but data transmission through the shield will not carry an EMP into EMP-protected spaces.

2.10.3 An EMP protected room-flood clean agent system shall be installed if EMP is a design threat.

Discussion. If a room-flood clean agent system is exposed to an EMP, its activating electronics could be damaged or destroyed. There is no data on how various clean agent activating mechanisms will fail, e.g., we cannot predict whether the systems will fail to discharge when needed or they will discharge immediately when hit with an EMP. Inside an EMP shield, these unpredictable responses should not happen. Outside an EMP shield, the electronics are vulnerable in the same way that FACSs just described are vulnerable. That is one reason why in Section 2.5 (Fire Suppression) a mechanical/pneumatic release for clean agent systems is required. Unless the activating electronics and its power supply are EMP protected, a risk exists that the electronics may dump the clean agent in response to an EMP.

2.10.4 A section of fire main shall be constructed of non-conducting piping, e.g., fiberglass where the fire main requires dielectric isolation in EMP protected facilities.

Discussion. A fire main constructed entirely of steel and routed through spaces that are not EMP protected can conduct EMP induced currents and voltages into EMP protected spaces if the fire main is not properly protected. In the event that the EMP protected volume in the underground is likely to be exposed to the very high currents associated with SREMP, the EMP protection engineer may install a non-conducting section of pipe in the fire main to provide dielectric isolation. In the event that the threat is HEMP, the specific EMP protective design depends on whether the fire main is a wet pipe or dry pipe system at the penetration point. This is because

water and air have different dielectric properties, i.e., the relative dielectric constant of water is approximately 80 times the relative dielectric constant of air. The cutoff frequency for the pipe at the penetration point is inversely proportional to the square root of the relative dielectric constant. The fire main is likely to have a diameter of several inches at the penetration into the EMP protected volume. If the fire main has a dielectric section, this opening will be transparent to a significant part of the HEMP environment. One option at the penetration point is to construct a welded array of pipes with a smaller diameter than the fire main which when filled with water have a cutoff frequency which protects against HEMP environments. The number of pipes in the array is determined by the flow requirements for the fire main. The individual pipes in the array can have a square or circular cross section. If square pipes are used, the interior dimension of each side has to be ½” 9`(~1.25 cm), each pipe has to have a minimum length of 3.5” (~9 cm) and the pipe array has to be continuously welded across all seams and continuously welded to the shield at the penetration point.

2.10.5 At least one fire pump should be powered by non-electrical means, preferably directly driven by its own diesel engine.

Discussion. This is not a substitute to replace fire pumps powered from emergency generators per NFPA 70, NEC Article 700. If the facility design threat includes EMP and utilizes a shielded volume to house mission equipment, HVAC and emergency generators, the fire pump and its controls should also be included within the protected volume. If they are not, then the fire pump and controls should be housed in a separate shielded volume with EMP-protected power provided by the generators within the shielded volume. The power feed can be through a filter/surge arrester combination installed at the shield boundary which is designed to survive the criteria (i.e., EMP current levels) from MIL-STD-188-125-1 associated with the length of the cable run between the primary shielded volume and the shielded volume containing the fire pump. The same type of filter/surge arrester is required at the power feed at the fire pump shielded volume. An alternative approach which eliminates the need for filters and surge arresters is to feed the power through a metal conduit which is circumferentially welded to the primary shielded volume and the shielded volume which house the pump and its controls. A non-electric directly driven fire pump provides a survivable fire pump (and sprinkler system) in the event of two types of failures; 1) it backs-up the emergency generators in case of damage to any part of the emergency generators or the electrical distribution system and 2) it continues to function in the event of an EMP event. This diesel driven fire pump has to be housed in a shielded volume to protect the controls on the diesel generator and has to have a protected connection to the controls within the shielded volume which has to have an appropriate battery flow to assure system activation and control when necessary.

2.10.6 Floor drains that penetrate an EMP protected volume should be protected by an EMP protection design.

Discussion. A floor drain which is welded to the shield at the penetration point, is less than 4” (~10 cm) in diameter and is at least 5 times the diameter in length is consistent with EMP protection requirements. However, if it is filled with water, the dielectric constant of water modifies the WBC characteristics and makes the drain opening transparent to part of the energy contained in the EMP. There are two solutions: make the drain long enough with continuous metal pipe such that the EMP energy is absorbed by the water or at the penetration boundary install an array of ½” (~1.25 cm) pipes with the length 5 times the maximum cross-section of

each pipe, and ensure that the pipes are continuously welded across the seams and continuously welded at the penetration boundary to the shield.

2.10.7 An EMP-protected smoke exhaust system shall be installed if EMP is a design threat.

Discussion. The smoke exhaust system shall be connected to a honeycomb waveguide array which is circumferentially welded to the shield at the penetration point and along all seams that would allow the EMP pulse to penetrate into the facility. The array can be constructed of square or circular pipes with the maximum diameter or side dimensions of 4” (~10 cm). If the array is constructed from square pipes, the minimum length is 7 times the side dimension. If the array is constructed using circular pipes, the minimum length is 5 times the diameter. The number of pipes in the array is determined by the smoke exhaust air flow requirement. If not properly protected, a smoke exhaust system routed to the outside or through spaces that are not EMP protected can conduct EMP energy into the protected spaces and disrupt any system to which the EMP energy can couple.

2.10.8 An EMP-protected pneumatic air system shall be installed if it operates fire/smoke dampers and EMP is a design threat.

Discussion. Generally, pneumatic air systems are erroneously considered impervious to transient power spikes that characterize EMP events. However, unless air compressors and their controls are EMP protected, the pneumatic air source may be inoperable. There are two basic ways to EMP protect fire/smoke dampers that are pneumatically operated: 1) install accumulators in the pneumatic air system (with check valves to prevent loss of pressure) if the air compressors are damage by EMP or 2) EMP protect the compressors. We recommend that both should be done because distributed accumulators also protect against airline ruptures that otherwise would drain the entire pneumatic air system. This guideline complements guideline 2.9.8 in Section 2.9 (Ground Shock).

2.11 FIRE LOAD CONTROL

2.11.1 Cabinet or closet storage for the estimated volume of required consumables should be provided and anchored against the design seismic load and ground shock. Fire-rated enclosures for oxidizers should also be provided.

Discussion. This guideline deals with a widespread architectural design weakness that has fire protection implications. The large majority of UGFs do not receive Fire Marshall inspections unless professional firefighters are part of the UGF staff. Operators of high security tenant spaces in a UGF resist allowing any fire inspectors into their spaces. Consequently, the occupants have little pressure to safely store their combustible consumables. The majority of all survivability assessments conducted have found significantly excessive fire loads. Much of the materials in these fire loads were legitimate to the operation, but they were stored in inappropriate or hazardous places and frequently in proximity to potential ignition sources. One hazardous fire load condition frequently found in electronic spaces is storage of cardboard boxes with equipment for the next scheduled upgrade. The primary reason that large quantities of exposed combustibles exists is that not enough cabinet and closet storage space is provided in the initial design for even the expected supplies. Any UGF that has a requirement to protect "x" number

occupants for "y" days needs consumable (typically burnable) supplies for "y" days (plus a safety factor) to ride out all contingencies that can be anticipated. When this stuff is brought into a UGF without adequate design planning, it ends up on bunks, on top of equipment, stacked in corners, along passageways under false floors, on top of air handling units, etc. where it can topple from seismic or ground shock and obstruct exit passages. This toppled fire load can also catch fire or it can sustain and enlarge an otherwise small fire. Most of this fire load is type A combustibles.

Fire load stored on top of equipment (particularly electronic equipment racks) is also stored closest to sprinkler heads, sometimes within 12 inches (~30 cm). If ignited, this fire load could activate sprinklers before smoke detectors can activate or the staff can respond with fire extinguishers. The proximity of that fire load potentially has the same effect as holding a candle to the sprinkler bulb. This is an architectural design problem as well as an operational problem with a fire protection implication. Designers should develop the most realistic storage volume estimates by consulting with experienced UGF operators. Estimates, based on precisely "x" occupants for "y" days will always result in underestimated needs because consumables are in constant use before a closed-door event occurs. That's why a safety factor of "y +" days is required so that with normal use, the stocked level never falls below "x" occupants for "y" days before restocking occurs. In addition, storage cabinets and racks should be anchored to adjacent permanent surfaces to prevent toppling during a seismic or ground shock event.

Smoke escape masks or Chem/Bio filter masks, O_2 candles and furnaces, CO_2 scrubbers and hoppers, Self Contained Breathing Apparatus (SCBA) and so on are generally Owner Furnished Equipment (OFE) to be provided after a UGF is built. Consequently, storage of these OFE rarely receives the design considerations needed to provide adequate storage or wall mounting space. Depending on the number of occupants and endurance requirements, significant quantities of O_2 candles or compressed gas cylinders may be stored in a UGF. NFPA 430, *"Code for the Storage of Liquid and Solid Oxidizers"* defines at least one Class III chemical component of O_2 candles. O_2 candles are oxidizers and they should be stored in dedicated enclosures that are fire-rated for oxidizer storage.

2.11.2 Raised or false floors should be eliminated wherever possible.

Discussion. Newer communications and computer equipment do not require the large under floor volumes of cooling air that older systems required. Newer designs have moved power supplies to the overhead and redesigned cooling cabinets that look like equipment racks. Raised floors are traditional storage places for consumables and spare parts. Space under raised floors is also a collection point for dust that can ignite explosively. A flag officer related that during the 1960s, in one of his country's UGFs, such an explosive dust fire under a false floor was the cause of four fatalities.

2.11.3 Storage of combustibles shall not be permitted along primary evacuation routes.

Discussion. POL storage tanks or warehouse type storage for consumables (unless the consumables are all metallic such a spare pipe, valves, etc., and out of their cardboard or wood containers) are an evacuation route fire hazard. Many of the blast producing design threats are also likely to ignite exposed POL and cardboard thereby obstructing these escape routes with debris and uncontrollable smoke. Unless the non-combustible consumables are restrained from toppling, they are also potential physical obstructions to evacuation. Gasoline or propane

powered vehicles should not be parked along evacuation routes or allowed inside a UGF for the same fire and physical obstruction reasons; see Section 2.13 (Natural Gas, Gasoline & Propane).

2.12 EMERGENCY POWER OFF (EPO) SWITCHES

2.12.1 EPO switches shall be installed in all critical electronic mission spaces. Modifications that bypass EPO switches shall not be made without the specific authorization of the AHJ.

Discussion. There are many instances of critical electronics spaces that were constructed without EPO switches or where equipment upgrades have bypassed the switches that were installed at construction. EPO switches are manually operated switches to deenergize all electrical power routed to equipment in a room where sprinklers are activating. These switches are required by codes to protect most electronically dense spaces such as communications, computer and TCFs. Their primary function is to prevent firefighters from coming in contact with live circuits and getting electrocuted. But, EPO switches do not disconnect ALL power. EPO switches do not disconnect the UPS batteries that may be installed at the bottom of electronic equipment racks from the equipment in the rack. These are generally low voltage power supplies, but never-the-less the equipment is electrically live. When sprinkler or fire hose water comes in contact with live electronics, the water may be conductive and result in shorting out the equipment. The conductivity of sprinkler or fire hose water is essentially an uncontrolled variable. It may go from low to highly conductive any time in a facility's life depending on the source for sprinkler water supply, how the water supply is treated and how long it stagnates in sprinkler and branch lines. Highly conductive water can be destructive to electrically live equipment. EPO switches deenergize higher voltage power supplies that are more likely to short out or threaten lives than lower voltage supplies. When these power supplies are deenergized before sprinklers discharge, it may be possible to dry out some of the less sensitive wet equipment that was not connected to rack mounted uninterruptible power supply (UPS) batteries and have some of it restored to operation. If the equipment is shorted out it may have to be replaced resulting in significant time delays before the mission is restored.

Generally, bypassing EPO switches is not a violation caused by the initial design engineers or installation crews. The violation occurs mostly during subsequent upgrades by the installing contractor or the operators in their zeal to minimize cost, system down time or an operator attitude that some equipment is too critical to deenergize automatically. This potential violation must be assiduously suppressed and corrected by facility managers or designated Fire Marshals. This violation is particularly common and potentially lethal where new spot-coolers are added to increase under floor ventilation. If ignition occurs in the false floor and all spot coolers are not instantly turned off with the EPO switch, then an incipient fire is supplied with a forced draft of fresh oxygen which can result in almost instantly filling the above floor space with smoke and causing occupant casualties.

2.13 SMOKE CONTROL

Smoke *control*, also called smoke management is much more complicated than smoke *extraction* or *exhaust* although smoke exhaust is part of smoke control. The emphasis here is on control, not just exhaust. Both the earlier and current edition of UFC 3-600-01 stipulated manually activated smoke exhaust systems for certain UGFs. The smoke issue for special purpose underground structures is to keep smoke from migrating and to contain it in the space or fire zone of origin until it can be exhausted. This is particularly challenging when the UGF has shut off outside air because it is hazardous. *Control* requires coordination with each of the following systems if installed, e.g., Building Automation System (BAS), Supervisory Control and Data Acquisition (SCADA) system, the Air Handling system, fire and smoke damper systems and ventilation intake and exhaust control valves. Thus, smoke *contro*l for a UGF is considerably more complex than a manually activated smoke exhaust system. Further, a smoke exhaust system, if not properly protected, can conduct an EMP treat into a UGF and disrupt or destroy mission equipment.

Smoke is not only the most significant life safety hazard; it is a hazard to mission equipment. It is that way everywhere, but smoke development and propagation in a UGF is different and potentially more destructive of equipment and threatening to life than it is in above ground facilities. This is because there are more types of burnable materials contained in a UGF than in above ground facilities. For example, diesel fuel is typically stored inside a UGF, but it is frequently stored outside office and headquarters buildings. When those materials burn in a UGF, there may be no place for the smoke to go except to fill up the space until forced air flow can be established to remove it. But, force air flow, i.e., smoke exhaust or purge may not be available during some closed-door operating conditions. If a fire occurs when the UGF is shut off from outside air, the primary option for smoke control is to contain the smoke to the fire zone of origin until the flow of outside air can be restored to the smoke exhaust system. Thus, under this closed-door operation the integrity of fire zone boundaries is critical for smoke containment. In general when a fire occurs inside a UGF, the smoke stays in the UGF until forced draft blowers can get make-up air to move it outside. Whereas, for above ground facilities, a burning building is already outside. When smoke or toxic fumes build up, firemen in above ground buildings can break a window to create cross ventilation. In a UGF, if combustibles are burning in an open-ended passageway (such as a vehicle tunnel that cannot be closed at either end) or open shaft, the flow of smoke may not be possible to control except with smoke curtains. Fire in a vehicle tunnel that is a primary access route could seriously impede or prevent evacuation.

2.13.1 UGF owners should periodically conduct an assessment of the smoke flow that can result from a fire in stored POL, consumables and other combustible concentrations.

Discussion. There are well established test procedures in NFPA 258, *"Recommended Practice for Determining Smoke Generation of solid Materials"* and a variety of ISO (International Organization for Standardization) standards to determine the quantity and characteristics of smoke that a small test sample of solid material will generate when burned. However, those procedures and results do not translate into a method for estimating smoke load in a building containing mixed burnables. NIST is conducting a project ("Validation of Bench-scale Smoke Toxicity Apparatus Project") whose objective is to complete development of a test method for

estimating the toxic potency of smoke from a burning building and furnishings. Whether that project or other ongoing research can scale their data up to reliably estimate the smoke load in a burning UGF remains to be seen. The purpose of this discussion is to inform the reader of the unsettled state of the art. However, there are established methods by which the migration and flow of smoke can be tested even if the smoke quantity cannot be estimated. Smoke exhaust systems are rarely tested after they are first put into operation. Thus, operators may not have an understanding of their smoke exhaust system's effectiveness after space and equipment modification have been made. This is an omission that can generate complacency about the potential smoke risks. It detracts from treating smoke control as the serious subject that it is and lowers priority for installing smoke control upgrades. Smoke migration and the smoke exhaust system should be periodically tested with a smoke generator. Periodically is taken to mean once every five years or sooner if there is a significant change in the fire load, space modifications or air flow.

2.13.2 The HVAC system shall be configured to automatically shut down air flow to a fire zone in which there is a smoke alarm.

Discussion. Smoke control means not only smoke removal, but preventing its spread or ingestion into other UGF spaces. Smoke's life threatening effects include obscured vision, clogged lungs with reduced breathing capacity and toxic combustion products such as hydrochloric acid. Smoke's mission threatening effects include clogged intake or recirculating air filters and soot. In addition to clogging filters, soot has an additional mission threatening characteristic. Soot quickly settles on all surfaces. In electronic equipment, those surfaces include circuit boards, electrical contacts and so on...and soot has a large carbon component. It is conductive and oily (sticky) thus, making it difficult to remove. Equipment containing minor soot deposits can short out when it is re-energized. Low voltage digital equipment is most vulnerable to shorting out from soot. What is little appreciated is that historically, in all types of facilities, about 2/3 of the smoke that affects electronic spaces originates from outside the space and about 1/3 from within the space. Further, NFPA 76 "*Standard for the Fire Protection of Telecommunications Facilities*" states (in Annex D) that it is estimated that 95% of the fire damage in telephone central offices is attributed to the smoke products and only 5% is caused by the thermal effect of fires. A telephone central office is a good analog for some of our electronically dense mission spaces. Therefore, the FPE must work with the HVAC engineer to design ventilation systems that adjust quickly to minimize the movement of smoke and to expedite its removal. The point of this guideline is to over pressurize the fire zones around the fire zone where smoke is generating so that the smoke is contained. This is why an earlier guideline in Section 2.1 (Fire Zones) requires fire zones to be coordinated with HVAC zones. Operators should have the ability to bypass the automated features of this system so that after automatic shutdown they can manually operate the ventilation system to focus its smoke extraction effects where it is most needed.

2.13.3 BAS or SCADA systems programmed to perform smoke control and other fire protection functions shall not be connected to outside monitoring capabilities.

Discussion. BAS (also called Building Management System (BMS)) and SCADA systems are increasingly being programmed to automate air handling, temperature, humidity, security, fire suppression, smoke control, pressurization and decontamination functions. Nominally, the purpose of a BAS or SCADA system is to reduce human error, speed responses to out-of-

tolerance conditions, reduce the need for trained on-site staff and permit monitoring and adjustment of controls by outside experts. These purposes do not necessarily work to the survivability advantage of UGFs. The vulnerabilities induced by a BAS or SCADA system are their complete dependence on automation and the potential for outside corruption or sabotage of UGF functions. While some dependence on outside experts may be unavoidable, connectivity outside the UGF to facilitate access of outside experts to internal systems is unacceptable. Where survivability is the primary consideration, the BAS or SCADA system should be expected to crash under the worst case. The potential to corrupt the automated responses of smoke control and fire protection systems by outside interference should be eliminated. Because BAS or SCADA systems interface with many other UGF functions (particularly Utilities) it may not be possible for fire protection to fully dictate the monitoring and control terms. Thus, the objective of this guideline is to ensure that there is no way that fire protection functions can be controlled from outside the UGF. If that objective cannot be accommodated, then automated smoke control and fire suppression capabilities should reside on a separate control system that cannot be managed from outside the UGF. Additional information about FACS software and where the FACS can be controlled is discussed in Section 2.15 (Manuals and Drawings).

2.13.4 A dedicated smoke extraction (exhaust) system shall be installed to:

- **route all fresh air to the smoke filled fire zone,**
- **shut down air recirculation in the affected and adjacent fire zones and**
- **exhaust 100 % of the air flow to the outside.**

Discussion. This guideline is one component of smoke control; it does not comprise a complete smoke control system. It adds some features and caveats to the existing UFC that requires a dedicated smoke exhaust system. It does not exempt single floor C4I UGF from installing a smoke extraction system. There may be circumstances where available space is too small for a dedicated smoke extraction system. In that case, careful integration of smoke controls with the exhaust ventilation system may be needed. Lack of a dedicated smoke extraction system is an undesirable arrangement and it should not be permitted in new construction. It may be unavoidable in upgrades of older construction where a dedicated system was never installed. Guidance for the design of smoke control systems can be found in NFPA 92A "*Recommended Practice for Smoke-Control Systems*".

2.13.5 Access ports should be installed in the smoke extraction (exhaust) system, the ventilation supply and exhaust ducts to accommodate hoses from portable smoke blowers.

Discussion. There will be many locations in a UGF where it is impractical to install dedicated smoke extraction ducts, e.g., the space between buildings built in a UGF and its tunnel walls. Ram fans, Red-Devil or similar blowers are portable and serve to fill the smoke exhaust gaps of the dedicated system such as unventilated or confined spaces. They also permit fresh air to be directed to specific locations or smoke exhaust to be conducted when dedicated exhaust fans do not function, when some portion of the supply or exhaust ducting is collapsed or when the ventilation exhaust system is designed to do double duty as a smoke exhaust system. In any event, the designer should install easily accessible and removable ports to accommodate the flexible supply and discharge ducts of portable blowers in both dedicated smoke exhaust ducts and the ventilation supply and exhaust ducts. If only one ventilation system is operational, it can be used in combination with the portable flexibility of the blowers, to remove smoke from any

localized area of the UGF. Several of these ports should be install in the smoke exhaust and air supply and exhaust ducts in each fire zone, depending on the size of the fire zone.

2.13.6 An EMP protected smoke exhaust system shall be installed if EMP is a design threat.

Discussion. If EMP Protection is a design criteria, the smoke exhaust system will need special design features that are discussed in Guideline 2.10.7 in Section 2.10 (EMP Protection) .

2.14 NATURAL GAS, GASOLINE and PROPANE

2.14.1 UGF equipment and vehicles shall not be powered by natural gas, gasoline or propane.

Discussion. The common gases that are used in kitchens and boilers and a variety of other commercial above ground uses are unacceptable in a UGF. Codes are clear about prohibiting their use during tunnel construction, but not for operations. NFPA 520, "*Standard on Subterranean Spaces"* is occasionally cited as permitting some hazardous liquids and gases in operating UGFs. But, that example illustrates how many codes, meant for civilian and commercial operations, such as highway tunnels are not applicable to the UGFs that concern us. The ambiguity between codes and the unique needs of special purpose UGFs creates a loophole that some UGF users have appropriated to introduce gasoline or propane into their UGFs. However, those liquids and gases are essentially potential bombs if distributed in air before ignition. As a rule of thumb, one gallon of propane (4.8 pounds/~2.2 kg) if distributed in air before ignition has the explosive power of one pound (~.45 kg) of dynamite. Readers should not be misled by assertions that propane or natural gas will flare and burn and not explode. This is essentially, but not universally true in open air. Propane, distributed in the confined space of a UGF (where its ignition can become explosive) is not the same condition as venting propane into an infinite air space. The flash point of gasoline is much too low to be allowed in UGFs. Another significant risk with these fuels is that WMD induced ground motion and EMP effects can create circumstances that can jolt or upend unsecured equipment, crush them with falling rock or concrete and/or create ignition sources from transient voltages and currents.

2.15 MANUALS and DRAWINGS

When upgrades or new construction are completed, contractors are generally obligated to leave owners and operators documentation in the form of As-Built drawings, O & M manuals and so on. The quality of that documentation has been almost universally deficient in its utility to operators. Construction and shop drawings are useful (primarily because they are the only available drawings), but they are not oriented to information that operators need. Fire protection drawings, in particular, are a hodge-podge of drawings scattered among different construction trades. Fire protection system O & M manuals are notorious for poor information quality; they generally contain very little about how the system is supposed to operate. That information is the designer's responsibility because he is the only one that knows how he intended it to function. The following guidelines cut across divisions between design and operating practices. Once contractors and their FPE leave a work-site because construction is complete, they do not

come back to develop necessary O & M material. These guidelines are collected here because they can be accomplished more efficiently if the fire protection system designer provides the recommended products before contracts are accepted as complete. The requirements for site-specific O & M manuals and related drawings must be spelled out very clearly in the specifications and pursued diligently during the work.

2.15.1 Manuals for a UGF's fire protection system should contain:

- **A description of how the fire protection system operates as an integrated system,**
- **A fault tree analysis that describes how the system will or will not function when individual components fail,**
- **Required actions to restore individual component functions under various failure mechanisms and**
- **An integrated maintenance schedule of all individual components in each system together with overall system test and maintenance requirements.**

Discussion. These guidelines do not exist in the current codes and literature, except in service specific Operation and Maintenance Support Information (OMSI) requirements. However, the specified documentation is crucial for UGF operators to develop responses and work-arounds when fire protection systems malfunction during a closed-door condition. Operators are operating engineers; they are not janitors, so in a closed-door operation, they are the available engineering talent as well as the firefighters. The FPE who developed the design is the one who best understands how he expects the systems he designed to operate. The facility operators do not; but they need that information for commissioning, initial operating or shake-down exercises, training, trouble-shooting and facility emergencies. The common practice is to assemble manufacturer's component literature as a substitute for system 0 & M manuals. This has been observed almost universally in U.S. and Allied UGFs. That product leaves operators with little information on how their system is supposed to operate **as a system** and especially what happens to the system when individual components fail, such as when the FACS logic is corrupted during a closed-door operation. Contemporary fire protection systems require simultaneous and reliable operations of multiple electronic systems. For example, activation of a room-flood clean agent response to a fire depends on the FACS, the SCADA (or BAS) system and clean agent suppression system for effective fire suppression. Smoke control is just as complex. Operation sequence notes are scattered among various construction drawings. Experience from a few attempts to assemble them into a single document show that they will not track as an integrated whole and do not provide a clear understanding of how a UGF's multiple interconnected fire protection and life safety systems are supposed to function. What operators need from design engineer is an operator friendly systems approach to fire protection O & M.

An operator friendly systems approach for the maintenance part of O & M has been recently published as UFC 3-601-02, *"Operation and Maintenance: Inspection, Testing, and Maintenance of Fire Protection Systems"*. The vacuum of what and when to test created by the large volume of unsatisfactory O & M products that contractors and their FPE have traditionally delivered has been partly bridged by this UFC. UFC 3-601-02 provides a single integrated manual that answers the questions of what and when to test it for just about every type of fire protection system. While the focus is not on UGFs, it applies to all UGF fire protection systems.

UGF operators should adopt this UFC as their basic fire protection O & M manual for maintenance (with any variations stipulated by contractor-provided manufacturer's information).

2.15.2 FACS software shall be backed up on site and a copy of the latest version of FACS software, password and loading instructions shall be retained in the UGF.

Discussion. Computers for FACS are the small memory chips inside the FACPs; they are not the typical servers that sit under a workstation. In case of a simple malfunction or corruption, FACS operation can be restored with a backup. Worst-case scenario for FACS is: 1) a WMD event, 2) FACS computer crashes and 3) there is only one master FACP. A backup will not help after a system crash. When a crash happens, information about how to program the FACS (which is what is typically found in contemporary O & M manuals) is useless. Further, the UGF will be isolated from the vendor that installed the FACS (or last upgraded it) and who also has the password for access. Vendors will not be permitted to enter during closed-door operations and in any event, access to the site may be impassable. Communicating with vendors is also problematic due to the possibility of saturated or destroyed phone connections, and/or the vendor's site or staff may be WMD casualties. In short, survivability of FACS software in the face of a worst case scenario requires that a copy of the latest software (together with the password to gain access) be retained on site so staff can reload the site-specific parameters and logic. The previous edition of the software should be retained until the newly installed version has demonstrated its reliability on site.

Section 2.4 (Fire Alarm Control System) recommends that an alternate master FACS panel be installed in a different fire zone then the primary and not be slaved from the primary. The alternate master FACS should be networked together with the primary master FACS. The redundancy and separateness inherent in that practice enhances FACS survivability and reduces the imperative for this recommend practice from a "shall" to a "should". However, if the alternate is slaved to the primary then a FACS crash will affect both primary and secondary and a useable software copy must be on site. A requirement to leave the software should be written into the specifications and may require negotiations with the winning vendor to be sure that they will deliver. Expect vendors to be resistant to leaving a copy of proprietary software out of their physical control. Vendor's anxiety may be alleviated by sealing the software, password and loading instruction (or the laptop with the hard-drive used to load the latest change) in a container to be broken open only when an emergency occurs. Periodically, when the vendor is on site to install the latest software upgrade, he should also conduct instruction on how to load it.

2.15.3 Construction drawings of all systems that affect fire protection should be delivered in AUTOCAD or GIS format, all referenced to the same basic floor plan and assembled into an integrated package of drawings.

Discussion. The relevant drawings are As-Built drawings. Those drawings that are related to fire protection have historically been scattered between HVAC, door and wall schedules, blast protection, CBR protection, architecture, plumbing, and other sections of standard A & E plans and drawings. Those drawings exist to facilitate installation and are thus, oriented to individual trades, i.e., they are construction drawings. When construction is complete, the 100% As-Built drawings, as they are normally assembled are not integrated by system and thus, are of low utility to the operators who need to understand the fire protection design as an integrated system. Drawings that should be included in an integrated package of fire protection drawings are:

- Architectural (fire walls, fire doors, wall and door schedules, evacuation distances, fire extinguishers, standpipe and hose cabinet locations),
- Structural (seismic and ground shock protection for fire mains and pumps),
- Plumbing (isolation valves, flexible couplings, fire mains, sprinklers and drain systems),
- Electrical (power supplies to FACS, fire and smoke dampers, remote isolation valves, auto-release fire doors, pumps, etc.),
- HVAC (AHUs, fire and smoke dampers, smoke exhaust systems, etc.),
- SCADA (controls for AHU, fire and smoke dampers, etc.)
- Fire Protection (sprinkler coverage, pre-action valve stations, room-flood clean agent systems, FACS and its control panels, fire/smoke detectors) and so on.

Basically, assemble and maintain all fire protection related drawings in a single package.

CHAPTER 3: LIFE SAFETY DESIGN GUIDELINES

3.0 APPROACH

Because staffs protected in Special Purpose Underground Structures are important to the continuity of their missions, the approach to life safety priorities are to provide a safe environment in the facility, a means to evacuate when necessary AND safe and to a means to shelter-in-place when it is not safe to evacuate. Existing codes abound to foster safe working environments and safe evacuation from hazardous facility emergencies. Life safety, in general, seems to be equal parts procedures and training as well as congenial designs to support safe individual responses. The primary authoritative references for safety in industrial facilities are the Occupational Safety and Health Administration (OSHA) Life Safety Codes. The National Fire Protection Association (NFPA) also has a large volume of code material in NFPA 101, "*Life Safety Code*" on life safety which is the primary basis of citations in the Unified Facilities Criteria (UFC). As with all codes, they are not adequate for UGFs that are potential targets of hostile actions or from which it may be lethal to evacuate during an internal emergency.

The unique features of UGFs and the extreme events imposed by the design threats require a tailored approach in order to achieve life safety priorities. The approach taken in this chapter is to assume that the majority of occupants are not thoroughly familiar with the UGF or its procedures. Thus, life safety features have to pass the idiot test. That is, when folks occupy a UGF because a WMD event has or may occur and they are already stressed. Protecting these folks while they are troubled by family concerns, claustrophobic reactions, mission emergencies and lack of familiarity with their surroundings and external events means that the life safety features need to be especially simple and easy to understand or operate. The existing Life Safety Codes are used only as a point of departure. Section 1.4 of the NFPA 101 encourages that departure under "Equivalency" in the following statement: "*Nothing in this Code is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed in this code"*. Most building and safety codes have similar caveats to encourage departures from rigid prescriptions to more performance based approaches for unusual facilities. The life safety guidelines in this chapter are one such departure. The goal is to permit occupants to safely escape or to shelter-in-place until rescued

under conditions of internal damage and complete loss of power. To achieve these goals the approach includes a spectrum of measures from additions to existing criteria, emphasis on, or upgrades to existing criteria and implementation practices to improve the effectiveness of commonly installed life safety equipment. Some of the proposed guidelines strengthen or restate existing code protections, i.e., they are designed to raise the bar on minimum requirements (e.g., from “should” to “shall”) as they apply to UGFs.

3.l EXITS and EVACUATION ROUTES.

Physical options for UGF entry and exit are restricted in number for security and survivability reasons. When facility emergencies occur, there are few evacuation options. Thus, well-marked exit routes accessible during all facility emergencies and threat conditions are needed to limit casualties and to forestall claustrophobic reactions. The nominal code requirements for providing exit and evacuation route markings do not take into consideration the unique UGF characteristics. For example, the definition of an exit does not necessarily mean the point at which an evacuee reaches the outside, i.e., the surface. Here, when used to calculate evacuation distances, an exit is a blast door that separates the protected UGF space from the effects of external blasts whether the distance from that door to the surface is 30’ or several thousand feet.

3.1.1 At least two separated walk-through exits shall be installed for emergency evacuation.

Discussion. Before shelter-in-place is discussed, provision to evacuate under day-to-day conditions must be established. These evacuation routes and exits also affect the location and design of safe refuges for shelter-in-place. The two ways out of a UGF should be as widely separated as possible. In addition to two walk-through exit routes and doors, there may be other exit options to provide greater emergency flexibility. One is to design a path through air intake or air exhaust if either is large enough to walk or climb through. The two walk-through exit routes are the basis of evacuation, particularly for evacuating non-ambulatory occupants needing assistance. Evacuation routes to exits should meet width and length specified in NFPA 101, *“Life Safety Code”*. Operators frequently install storage cabinets along these evacuation routes which undermines life safety because they may contain fire load, hazardous substances or substances that become hazardous if ignited and can topple and block escape routes. Those substances should not be stored in evacuation routes. Designers need to coordinate the objective to contain fire load in storage cabinets or closets, discussed in the Fire Protection Guidelines under Section 2.11 (Fire Load Control) with evacuation route designs. Operators need to ensure that if cabinets are installed along the evacuation routes, the remaining width is adequate to meet code requirements. All cabinets should be firmly anchored to the floor and wall to ensure that they cannot topple over from seismic or threat induced ground shock and obstruct the evacuation route.

3.1.2 At least one emergency escape hatch or passageway should be installed.

Discussion. Escape trunks or hatches should also be provided where feasible because the surface may be obstructed with debris and the doors at the walk-through emergency exits may be damaged and inoperable from one of the design threats. Rescue teams can clear the debris and open a path to rescue the occupants if a reinforced escape hatch from the UGF leads into an

access tunnel or is installed near the surface. The escape trunk and hatch frame should be at least as structurally hard as the UGF. If feasible, it should also be large enough to allow passage of a stretcher (gurney) through the trunk and hatch.

3.1.3 In certain circumstances, the opening direction of escape route doors may conflict with the direction specified in life safety requirements. Evaluate these conflicting requirements individually.

Discussion. Protection against airborne WMD agents requires maintenance of internal overpressure to prevent infiltration of lethal media. Escape route doors are specified in life-safety codes to open outward to facilitate movement of an evacuating crowd. But, that opening direction could compromise the ability to hold an overpressure. No matter which way doors in the evacuation route open, they should automatically close on a fire/smoke alarm. For inward closing doors, consider increasing the fire rating above the rating that would normally apply. Where there is space, additional safety features such as an air lock should be considered where one door has to shut before the other can open. These additional features can be combined with other protective features such as EMP or Blast doors that can also serve the purpose of an airlock. If a UGF does not contain an internal hazard that should be prevented from escaping, there are several options for satisfying the need to maintain overpressure and life safety. In small facilities that means that some escape route doors designed to open outward need to be designed with a tight seal so that over pressure can be maintained against the door. Where overpressure will blow open the door with enough force to endanger entering staff, an airlock can be used to maintain the outward opening direction. However, there are circumstances where the final door in the exit path must open inward; ammunition storage sites are an example. NATO and the U.S. store a variety of explosives in UGFs where blast doors (which are typically the final evacuation route door) open inward to keep an internal accident from blowing out the door and hazarding the neighborhood.

3.1.4 Fire and smoke protected elevators should be installed where elevators are required.

Discussion. Some UGFs may require elevators for access. In general, the U.S. fire protection custom is to prohibit the use of passenger elevators for evacuation during fires. However, all U.S. passenger elevators are configured so that firefighters can recall them for manual operation using a special key. Relocation personnel may not consist exclusively of young healthy military personnel, but may also include senior advisors that may be disabled, elderly or chronically weakened individuals. If casualties occur in the UGF, it may not be possible to extract the disabled via stairways or ladders. Or, carrying non-ambulatory individuals up stairways may be too time-consuming to save them or prevent extending their injuries.

Investigations into life safety improvements following the collapse of the World Trade Towers have led the National Institute of Standards and Technology (NIST) to recommend the use of "protected" elevators in future elevator designs in order to speed the evacuation of the disabled. While "protected" does not mean fire-proof, it means that features that allow safe operation in many fire and smoke conditions are incorporated into the design. These features include smoke proof hoist ways, protected lobbies, two-way communication, back-up power and protection against water in the hoist way and power panels. Protected elevators are already required by some European and Far Eastern building codes. While protected elevator technology is established, it is not yet required by U.S. building codes. Considering the importance of the

relocation staff to mission continuity, installation of protected elevators in UGFs would be prudent. Where elevators are required, at least one should be large enough to carry a stretcher (gurney). If the design threat includes aircraft impact, elevator pits should be designed large enough to contain the fuel quantity that may flow into the UGF.

3.2 SIGNAGE

In general, the safety signs required by code are not good enough to support life safety in cold, dark, quiet and smoky UGFs. That's the environment that the designer should consider when signage design is on the table.

3.2.1 Especially clear, uncomplicated attention-getting instructions for entering or exiting the UGF shall be posted at entrances and exits.

Discussion. Entrants are either fleeing a potential threat or the effects of a threat that has already materialized. Easing the flow (in either direction) of the relocation staff through the doors, security check points, decontamination facilities or any other entry/exit hurdles requires easy-to-follow signage. Entering staffs are likely to be anxious, impatient and hyper to make things happen and they may have to do it on their own with only posted signs as their guide. Operating staff may be encumbered by other facility duties or emergencies and be unavailable to provide on-the-spot directions to entering staff. Some of these same conditions pertain to occupants fleeing an internal threat such as smoke or fire. Without clear, unambiguous instructions (posted or verbal), the potential for panic in a facility emergency will increase. Therefore, based on the posted instructions, exits should be operable by untrained occupants without the need for special knowledge or effort. The clarity of those instructions should be periodically tested by someone who is not familiar with the facility such as a newly assigned staff member.

3.2.2 "You are here" diagrams oriented to each location and viewing direction shall be mounted at frequent intervals and at all intersections in large sized copy and print showing all the rooms, their numbers as well as primary and secondary escape routes.

Discussion. After occupants have passed through the entry process, they have to find their way around and also find the evacuation routes. Ensure that the distinction between primary and secondary evacuation routes on the "you are here" diagrams is unmistakable in low light. Individual “You Are Here” signs should not simply replicate a single floorplan if that floorplan is not correctly oriented to the location. Exceptions and simplified diagrams can be made for OpSec reasons in visitor-permitted areas.

3.2.3 Each room door shall be marked with large, luminous alpha numeric designation that follows clear location logic.

Discussion. Each room door should be clearly identified in large block letters not only to aid the occupants in finding their destination, but so that rescue and extraction teams working in smoky corridors and who have never been in the UGF can identify where to find (or where they found) casualties. These markings should be no less than 2 inch high alpha-numerics. The logic for room numbers should track some system that is obvious to external rescue teams such as "U123" for room 123 on the upper floor or "LN123" for room 123 on the lower floor in the north corridor. The luminous requirement is also to aid the rescue team. Luminosity can be provided

by either reflective or photo luminescent materials or any other material whose outlines will jump out under flashlight or low light conditions.

3.2.4 High visibility primary and secondary evacuation route markings shall be installed on or near the floor.

Discussion. Code required ceiling mounted "EXIT" signs work fine in non-smoky conditions. These should be installed according to code. However, the design goal for life safety is to guide the occupants to safety under the worst-case conditions, i.e., cold, dark, quiet and smoke filled. Code compliant “EXIT” signs are not useful in this environment. Route markings mounted near the floor are more likely to help evacuees under smoky conditions than the ceiling mounted exit signs. Aircraft put their exit path lighting on the floor for these reasons. The evacuation routes referred to here are not just to the surface, but to any shelter-in-place safe refuge. High visibility can be provided by either lighted or photoluminescent materials. Where more than one color is available, arrows showing the primary escape route should be in a different color than those showing the secondary escape route. These same materials should prominently mark the exit doors along the evacuation route so that evacuees do not take a wrong turn in the dark or smoke. The color of the Exit door markings should match the escape route markings that they serve.

Exit route and door color schemes can lead to confusion. Various agency, services and governmental entities have all weighed in with differing versions of acceptable colors for their specific applications. OSHA publishes several widely available guides. In general, red is for firefighting equipment, yellow warns of physical hazards and green is for first aid. There is no recognized guidance for the color or shape of exit route and door markings. In the absence of clear direction, we suggest that the primary exit routes and doors should be marked with a heavy or solid green photoluminescent tape and secondary route and doors should be marked in a different color (if available) or in a dashed or narrow green photoluminescent tape or paint that clearly distinguishes primary from secondary. Where photoluminescent tape costs are an issue, route markings need not be continuous, but individual route marking segments should be no further apart than 10 feet (~3 meters). Exit doors should have the same colored photoluminescent “EXIT” sign in large letters plus photoluminescent stripes across the door’s diagonal. We also recommend that if any DoD organization operates more than one UGF, they should all adhere to the same color code. If that organizations’ operators, mission staff or security personnel need to serve in any of those UGFs, there is no confusion during a facility emergency about what color means what.

3.2.5 All safety related equipment, exit doors and safe refuge doors should be marked with high visibility materials that can be seen in the dark.

Discussion. Safety equipment such as smoke escape masks, first aid kits, fire extinguishers, pull boxes and so on are rarely marked so that they can be found easily in the dark or smoke. Some Scandinavian ships follow the practice of outlining all safety equipment in color coded photo luminescent tape. This enhances the speed of life safety responses particularly for uninitiated occupants moving under obscured light conditions by eliminating groping in the dark. This practice not only facilitates safety in dark or smoky conditions, but occupant’s attention will be

drawn to the location of the nearest safety features when they are walking about at night during normal operations.

3.2.6 Accesses to Confined Spaces shall be marked with appropriate warning signs.

Discussion. Some UGFs have small, difficult to exit spaces that meet the NFPA criteria for confined space. Signs that identify a space as a "Confined Space" and warn of the hazards, (such as accumulated gases) and list site-specific safety procedures should be posted on any accesses to these spaces. Safety codes require these warning signs, but they have not been universally used.

3.3 SAFE REFUGE

The worst case condition may require the UGF occupants to shelter-in-place. The safe refuge described here is not the area of refuge required by NFPA 101, *"Life Safety Code"* to protect occupants in an elevator lobby. The safe refuge referred to can be any part of a UGF that has some additional characteristics to sustain a shelter-in-place option. In order to make shelter-in-place feasible, there needs to be a least one well protected space in UGFs under 50,000ft^2/~4645m^2 of gross floor area and two in larger ones. That is, safe refuge spaces should have strong resistance to facility emergencies such as fire and should sustain the occupants until it is safe to evacuate. Facility emergencies that would force occupants into these special spaces are similar to those associated with trapped miners, except that in the case of UGF occupants, the surface may be lethal even if evacuation routes are clear. The 50,000ft^2/~4645m^2 gross floor area values used to specify the number of safe refuges is an approximation. The type and quantity of life safety equipment provided in them should be based on the owner's judgment. That judgment should take into account the number or occupants, the design occupation time and expected response time of rescue teams. It could take rescue teams some time to decontaminate the surface area, clear debris and break into the UGF. Under the best conditions, rescuers could be inside within hours; under difficult conditions, they could take up to a week. That time depends almost entirely on what the threat did to the surface approaches to the UGF.

3.3.1 At least one internal safe refuge should be designed to sustain occupants for three days in bunker facilities and one week in tunnel facilities.

Discussion. These protected zones should be fire zones designated as safe refuges and outfitted with special equipment to sustain the occupants until evacuation is feasible or rescue teams can free them. Some of the desired fire protection characteristics of these safe refuges were discussed in the Fire Protection Guidelines under Section 2.1 (Fire Zones). A safe refuge zone should contain emergency equipment similar to those used in mines. For example, the availability for fresh outside air is not reliable. The external air supply may be lethal or cut off. Therefore, a safe refuge should contain an engineered fresh air system such as carbon dioxide (**CO_2)** scrubbers and oxygen (**O_2)** generators. It should also have stocks of life safety and first aid supplies, food, water, blankets, field expedient toilets and communications to the surface. Carbon monoxide (**CO)** removal on a continuous scale is well developed for submarine applications. The submarine equipment requires power; it is not available commercially. Individual protective masks that use hopcolite to remove **CO** for a short period are commercially available. They are commonly associated with mine safety and escape. When activated, their useable endurance is short (up to an hour) and they can generate high temperatures at the user's mouth. Currently,

there are no commercially available options to remove **CO** from a room sized safe refuge space. Some limited options are being developed, but they are expected to require power. The current lack of options to remove **CO** from room sized spaces remains a life safety weakness.

The one week maximum endurance time for tunneled UGFs is based on the estimated time it would take for rescue teams to: 1) clear a safe path through approach obstructions and WMD contamination, 2) dwell on-site to clear collapsed surface building structures, 3) locate or excavate an entry point such as the escape hatch, 4) cut through or force entry through deformed blast protection and 5) work their way through internal obstructions and smoke to find surviving occupants. Recent highly public efforts to rescue trapped miners indicates that provisions to sustain survivors for more than a couple days is more consistent with the longer times that it might take to effect a rescue in tunneled facilities. If a preexisting emergency exit can not be found or used by rescuers, rescue may depend on the speed of penetrating some portion of hard rock. Breakthrough time to penetrate a bunker and rescue survivors should be less complex and not as dependent on locating an emergency exit as it is for tunneled UGFs. Three days should provide adequate time for rescue teams to force an entrance through any portion of a bunker's concrete roof.

3.4 ATMOSPHERE MONITORING & CONTROL

There are two types of atmosphere monitoring to be considered in a UGF; a permanently installed monitoring system and portable equipment to test for specific gases in localized areas. Permanently installed monitoring equipment tests the overall atmospheric health of a UGF by positioning the detectors at locations where the staff frequently congregates or regularly traverses. The atmosphere monitoring panel should be located at a constantly attended location where its indications and alarms can be monitored 24/7. This is similar to the requirements for monitoring the Fire Alarm Control Panel. Portable equipment is used when atmospheric quality at a particular location is suspected of being foul (such as in a confined space or a packed conference room) and the location is not monitored by the permanently installed system There are also two kinds of atmosphere control to be considered in a UGF; collective air quality and individual air supply. Collectively, HVAC systems recirculate about 90% of internal air and refresh it with 10% outside air (i.e., make-up air). As a reference point, this ratio is similar to most above ground office buildings. However, some of the design threats may either physically block air intakes or result in surface air quality that is too poor to ingest into the facility as make-up air. For the purposes only of calculating survival requirements, it should be assumed that as soon as occupants enter a UGF, the surface air refreshment option is foreclosed and the occupants will have only the residual air mass to breath. An occupancy design goal of "x" number of people for "y" days or weeks is usually specified in design documents. However, just as the best laid war plans do not survive the first engagement with the enemy, occupancy design numbers are flexible and subject to "adjustment" depending on the actual conditions at the time of an emergency. Designers should plan for more people to occupy the UGF than initially anticipated. From a life safety viewpoint atmosphere control in the UGF is about air revitalization without external makeup air. The primary considerations are to provide oxygen and to remove carbon dioxide from all the occupied spaces with special considerations for the safe refuge areas.

3.4.1 Atmosphere monitoring equipment that samples the three primary gases (O_2, CO_2 and CO) shall be permanently installed at several locations and centrally monitored.

Discussion. Permanently installed monitors alert operators to unanticipated accumulations of hazardous gases. They can be viewed as the electro-mechanical equivalent of canaries in coal mines. They should be installed in spaces and corridors where the staff spends most of its time or where the staff is likely to congregate during a closed-door event. As a minimum, the baseline for day-to-day atmospheric health is established by the three gases cited in this guideline. Elevated levels of CO_2 and CO are both lethal and O_2 is the primary gas that supports life. That leaves out the gases and contaminants that make up the chemical family that are covered by NBC protection guidelines which is where the reader should go for discussions of monitoring equipment for those WMD media. Hydrogen (H_2) should be monitored if UPS batteries can off gas hydrogen during their charging phase. A four percent concentration of H_2 is an explosive mixture. Other gases, such as volatile organics (e.g., methane or sewer gas) and Nitrogen Oxides (NO_x) may be monitored depending on the potential for their existence in the staff spaces or infiltration into the UGF. However, if methane, NO_x or any other gases are monitored they shall be monitored in addition to and not instead of any of the three primary gases. The preferred location for a primary atmosphere monitoring panel is in close proximity to the primary Fire Alarm Control Panel (FACP). An alternate atmosphere monitor panel should be located with the alternate FACP. Preferably it should not be slaved to the primary atmosphere monitor panel. If EMP is a design threat, this system may need EMP protection, see Section 3.6 (EMP protection).

3.4.2 Portable atmosphere monitoring equipment should be available to test for all anticipated hazardous gases.

Discussion. Portable detectors to test for the three primary gases monitored by the permanently installed equipment form the core of this life safety equipment. Portable equipment is used where the permanent equipment is not installed and where there is a suspicion that the air quality could be unhealthy. As to the need for portable equipment to test for any other gases, this is an intentionally ambiguous guideline. Each UGF should develop its requirements based on the proximity to contaminating gas sources, its endurance requirements as well as a menu of toxic industrial gases that terrorists may appropriate. Both the permanent and portable atmospheric monitoring equipment are used to determine when to start atmosphere control equipment.

3.4.3 Oxygen replenishment and CO_2 scrubber capability to support 150% of designed occupancy for the designed occupancy period should be provided for the entire UGF.

Discussion. There are a variety of design choices to provide air revitalization. Oxygen can be provided by $\mathbf{O_2}$ candles, compressed gas cylinders or liquid $\mathbf{O_2}$ cylinders. Each choice has its own pros and cons; none require power to distribute $\mathbf{O_2}$. However, in the safe refuge, the compressed gas cylinder may be the least complicated way to provide the O_2. In any event, O_2 sources should be stored in protected enclosures to avoid accidental release or activation. Protected enclosures mean protection from both fire and physical damage such as from fallen rock. Open storage of O2 cylinders and canisters in common access areas is not considered a safe practice.

Carbon dioxide removal presents different issues. In-line “scrubber” systems can be incorporated into the air recirculation system, lithium hydroxide (Li (OH)) canisters can be used in portable **CO_2** scrubbers and Li(OH) “curtains” may be hung vertically. For the first two options power is needed and it may not be available. Li (OH) granules from canisters or from in-line **CO_2** scrubber containers can be spread out on flat surfaces (preferably plastic covered) when power is not available. However, this can be messy, hazardous to skin contact, irritating to bronchial passages from Li (OH) dust inhalation. The spread out granules can interfere physically with the limited space in a safe refuge. **$C0_2$** absorbing strips or curtains can be hung up when power is not available.

3.4.4 Oxygen stored in candles or cylinders and portable CO_2 scrubber equipment to sustain at least one week of occupancy in a tunneled UGF and at least three days of occupancy in a bunker should be provided in the safe refuge spaces.

Discussion. These **O_2** supplies and **CO_2** scrubber quantities stored in the safe refuge spaces should be part of the previous guideline for storing quantities to support 150% of the design occupancy load. Conditions in a safe refuge space could be crowded and tense if the occupants are waiting for rescue. **O_2** candles could be a hazard in these conditions. A simple cylinder of **O_2** may be the more effective and least complex solution. However, **O_2** cylinders can become a fire hazard. Neither option is without drawbacks. A newer generation of **CO_2** absorbing agents is a rolled up continuous thin layer of material that can be removed from their canisters and hung vertically or laid out on a flat surface when there is no power. Other forms for using Li (OH) include curtains and battery powered absorbers. This is the preferred **CO_2** removal system in that it provides the least hazard and greatest flexibility for use under a wide variety of adverse conditions. The objective for atmosphere control in a safe refuge space is to sustain life for the length of time it may take an external rescue team to the reach the occupants while minimizing the occupant's efforts and risks to revitalize their own air.

Providing safe air for people that must temporarily operate in or traverse a space with unsafe or uncertain air quality requires individual air supplies. Smoke escape masks or Chem/Bio filter masks are Owner Furnished Equipment (OFE) to be provided at Initial Operating Conditions (IOC) and do not require special design considerations. However, as a note of caution, until a universal mask is developed, smoke escape masks and Chem/Bio filter masks have limitations and they should not be used interchangeably. Self-Contained Breathing Apparatus (SCBA) is needed by the operating staff for fire fighting and for investigating and controlling other internal hazardous conditions. The operating staff also needs to be able to guide community emergency responders or rescue teams through smoke filled or other hazards to the scene of any accident or fire. The wall space to mount SCBA equipment and spare air bottles is modest, but does need to be considered in the design. The number of SCBA equipment that should be mounted on the walls will vary from UGF to UGF depending on the number of individuals who may have to stay behind for more than a few minutes in a hazardous condition.

At least four spare charged air bottles should be provided for each SCBA if the UGF does not have the capability to recharge SCBA air bottles. SCBA charging equipment should be installed in larger sized UGFs (i.e., greater that $50{,}000ft^2/\sim 4645m^2$) or in UGFs with extended underground distances between the two furthest entry points. This number of air bottles accounts for extended SCBA use for a variety of tasks including; 1) fire fighting, 2) search and rescue of

trapped occupants, 3) providing any casualties with air while they are being carried out, 4) mission staff remaining behind to transfer functions or shut down equipment, 5) escorting community firefighters, 6) providing on-site security while fire fighting operations are conducted as well as 7) a safety factor in case the community firefighter's air bottles are not compatible with the UGF’s air bottles. Adequate wall space to mount the SCBA for quick access needs to be provided in each separate fire zone.

3.5 COMMUNICATIONS

3.5.1 At least one system shall be installed that can be used to broadcast safety instructions throughout the UGF from the Control Room and its alternate location.

Discussion. Occupants need to receive information and safety instructions during a facility emergency. They need to receive those instructions anywhere they may be in the UGF. The operating staff in the Control Room is in the best position to assemble a picture of the UGF's condition and developing hazards. "Control Room" is used loosely here and it means wherever there is 24/7 monitoring capability of the UGF's safety condition including a Fire Alarm Control Panel (FACP) and atmosphere monitoring panel (NFPA also calls this location the “Fire Command Center”). What is needed is a public address or general announcing system whose speakers are ubiquitous in the UGF. Such a system can be a dedicated stand-alone system or it can be incorporated in the fire alarm system if that system has speakers installed throughout the UGF. Or, it could be both and one system backs up the other. If EMP is a design threat, this system may need EMP protection which is discussed in Section 3.6 (EMP protection).

3.5.2 Communications aides should be installed to facilitate UHF RF communications throughout the UGF.

Discussion. The ability of emergency teams to coordinate their actions is critical to efficient responses during a facility emergency. Firefighters, Emergency Medical Technicians (EMT), security forces, operators and rescue teams all use Ultra High Frequency (UHF) radio "bricks" for this purpose; some encrypted, some not. These UHF bricks can go anywhere and until their batteries run out of charge they are independent of power supplies. The very nature of a UGF is hostile to the propagation of radio frequency (RF) communications. Rock, concrete, Electromagnetic Pulse (EMP) protected enclosures and other metallic interferences create "dead zones" or degrade internal RF communications. When a Command Center is set up outside a UGF to coordinate responses to a UGF facility emergency, communications to coordinate between above ground control and below ground emergency responder teams can be impeded if RF propagation in the UGF is not aided. One solution for providing this aide is a "leaky" line antenna, but other mechanisms, such as relays are also feasible. If EMP is a design threat, this system may need EMP protection which is discussed in Section 3.6 (EMP Protection).

3.5.3 Emergency telephones connected to the Control Room and its alternate should be installed every 500 feet (~150meters) in primary and secondary escape routes.

Discussion. If occupants have to evacuate during or after a threat event, they may be blocked from making a complete exit by falling debris, smoke and fire, or obstructions along the route or at the exit point. These evacuees need to be able to communicate their status and location to potential rescuers or to warn follow-on evacuees of the hazards en route. Provisions should be made to switch the emergency telephones to a designated external drop.

3.6 EMP PROTECTION

The effects of EMP are not typically considered when designing life safety systems. The typical life safety systems that can be affected by EMP include atmosphere monitoring systems, communications systems used for Public Address (PA) and emergency communications between external emergency response Command teams and internal emergency response teams. If the life safety system has to connect across an EMP boundary, EMP protection techniques are needed to ensure that it will function after an EMP event. Just as with fire protection systems, life safety systems have not been systematically tested to determine their exact response to an EMP, i.e., to determine whether the systems would short or open. The exact mechanism of disruption is irrelevant in that the affected systems exposed to an EMP will be disrupted and possibly permanently damaged. EMP is the kind of threat that can couple from one conducting system to another and so it takes just one inadequately EMP protected conduit to put all other systems at risk of disruption. EMP generally refers to nuclear or non-nuclear electromagnetic pulse effects. It is a burst of electromagnetic radiation from a high energy explosion, particularly a nuclear explosion. It can also be caused by a non-nuclear event that causes an instantly fluctuating magnetic field. Unless the observer is very close to lightning, lightning also produces an EMP effect that is substantially weaker than the nuclear generated EMP effects. The term EMP most commonly refers to a wide area electromagnetic pulse generated by a high altitude nuclear explosion above 25 miles (~40 km) height of burst which is usually defined as HEMP. Another nuclear event that causes an EMP is a ground burst nuclear explosion that generates a source region EMP known as SREMP. These events, HEMP and SREMP couple to any exposed conductor, e.g., wires and pipes and induce very high voltages and currents that disrupt or damage unprotected electronic and electrical equipment. Fire protection systems not designed with effective EMP protection cannot only be affected in response to an EMP event; they can also be the conduit to damage or disrupt other systems. Each of these EMP phenomena has somewhat different and complex characteristics. Protection against them requires highly specialized designs and maintenance practices. A more detailed discussion about HEMP and SREMP characteristics that life safety engineers need to understand for application to special purpose UGFs with an EMP protection design criteria is contained in Appendix A (EMP Effects) to the Fire Protection Design Guidelines. Guidance on how to design EMP protection is contained in MIL-STD-188-125-1 (DoD, "*HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) PROTECTIONS FOR GROUND BASED C4I FACILITIES PERFORMING CRITICAL, TIME-URGENT MISSIONS PART 1 FIXED FACIITIES"*, MIL-STD-188-125-1 of 17 July 1998. The following describes life safety systems that could be affected by EMP and what, in general, should be done to protect them.

WARNING: The effectiveness of all EMP protected life safety systems described in this section should be verified, prior to putting the UGF in service, using the testing protocol provided in Appendix A to MIL-STD-188-125-1. In addition, to prevent deterioration and compromise of the EMP protection, the associated Hardness Maintenance/Hardness Surveillance (HM/HS) procedures should be incorporated into the overall HM/HS plan.

3.6.1 When EMP is a design threat, an EMP protected atmospheric monitoring system shall be installed.

Discussion. Atmospheric monitoring stations (detectors) located inside the EMP shield, can use copper cables to connect to the internal monitoring panels. For atmosphere monitoring equipment located outside the EMP protected volume, a copper to fiber-optic cable conversion should be made interior to the protected volume. The fiber-optic cable should be fed through a WBC which is circumferentially welded to the shield at the penetration point. The diameter of the WBC pipe shall not exceed 4" (~10 cm) and the length of the WBC pipe shall be at least 5 times the pipe diameter. The associated HM/HS procedures should be incorporated into the overall HM/HS plan. Notice that in the following guidelines the requirements for fiber to copper, WBC, circumferential welding and HM/HS plans are similar for all systems that connect signal lines across the EMP shield boundary.

3.6.2 When EMP is a design threat, an EMP protected Public Address system shall be installed that can be used to broadcast safety instructions throughout the underground facility.

Discussion. If the UGF has an EMP protection requirement, the Control Room should be within the EMP protected volume. Within the protected volume, copper cable can be used to connect to the public address (PA) speakers. At the shield boundary, a copper to fiber-optic cable conversion should be made interior to the protected volume. The fiber-optic cable should be fed through a WBC which is circumferentially welded to the shield at the penetration point. The diameter of the WBC pipe shall not exceed 4" (~10 cm) and the length of the WBC pipe shall be at least 5 times the pipe diameter. On the outside of the shield, a fiber-optic cable to copper conversion with appropriate power will allow the external speakers to be powered. However, in an EMP event, one should not expect the PA system outside the shielded volume to survive unless the design takes into account the need to extend the EMP protection to those speakers. One such technique would run the copper power cable to each speaker and enclose them in small, welded conduit connections to each speaker location and place the speakers in a welded metal box with a small honeycomb WBC in front of the speaker section. The pipe should be circumferentially welded to shield boundary and the cable penetration point into each box containing a speaker. Once installed, the PA system should be tested at the protected volume penetration point and for each external speaker that has been protected using the protocol provided in Appendix A, MIL-STD-188-125-1. The associated HM/HS procedures should be incorporated into the overall HM/HS plan. If properly designed, the wires connecting to the protected speakers can be used as a Shield Enclosure Leak Detection System (SELDS) test device for the welded conduit run.

3.6.3 Where EMP is a design threat, EMP protected communications aides should be installed to facilitate VHF/UHF RF communications throughout the UGF.

Discussion. If there is a need to communicate via VHF/UHF from outside the facility to the Control Room or to any other location within an EMP-protected volume, a leaky antenna to fiber-optic conversion has to be performed external to the shielded volume and the fiber-optic cable fed through a WBC which is circumferentially welded to the shield at the penetration point. The diameter of the WBC pipe shall not exceed 4" (~10 cm) and the length of the pipe shall be at least 5 times the pipe diameter. Interior to the shielded volume, convert from fiber-optic cable to a leaky coax with an appropriately powered signal repeater to provide internal connectivity.

Once installed, the leaky coax to fiber-optic conversion and penetration through the shield should be tested at the protected volume penetration point using the protocol provided in Appendix A, MIL-STD-188-125-1 and the associated HM/HS procedures should be incorporated into the overall HM/HS plan. However, since the external leaky coax system cannot be protected, it cannot be expected to survive an EMP event.

3.7 ACCOUNTABILITY

When a facility emergency requires the occupants to move to a safe refuge space or to evacuate, being able to account for all hands is a must in order to determine if and where search and rescue may be required. In the comings and goings confusion of an emergency relocation event, executing early actions to prepare for evacuation accountability is typically not high on the priority list.

3.7.1 An evacuation accountability system should be installed to identify potential casualties.

Discussion. Accounting for who is safe and who may be left in a hazardous area is generally conducted by sight. For UGFs, the reliability of this operational practice can become complicated and potentially ineffective. Undocumented individuals that have evacuated from the UGF and kept on going, either because they were spooked or went elsewhere to support leadership make a sight count (muster) unreliable and iffy at best. There are several design features that can facilitate better accounting practices for occupants in an emergency. One way is to have all hands badge-in **and** badge-out. (The security team will need to enter the names of unbadged entrants in a computer data base to establish a "baseline" at the beginning of relocation operations). Since there are generally very few exits, badge readers or voice recorders located inside the blast doors of those exits could facilitate badge-out accountability. At one NATO UGF, the badge-out system was programmed to print out, in an emergency the names and locations (where individuals last badged-in) of the individuals remaining in the UGF. Turnstiles may be designed to incorporate badge readers or other accountability schemes. Whatever individual identification scheme the relocation staff uses is the limiting mechanism around which to design an accountability scheme. Frequent improvements in low-impact electronic accountability systems seem to be a characteristic of security systems so that it is not possible to suggest any particular approach; just that whatever system is chosen, it should be part of the life safety design. Because automated systems located at the entrances may be damaged by external treats, such as EMP, or rendered inoperable by power or connectivity disruptions, these systems need to be easily shifted to manual operation. This design should be coordinated with the security staff.

END

APPENDIX A

ELECTROMAGNETIC PULSE (EMP) EFFECTS

Introduction

It has long been known that conventional explosions can produce electromagnetic signals. Therefore, it was not unexpected that nuclear weapons would produce a much more intense electromagnetic signal, i.e., an Electromagnetic Pulse (EMP). EMP can induce high transient voltages and currents in conductors connected to equipment and disrupt and/or destroy sensitive electrical and electronic equipment. Depending upon the burst location relative to the earth's surface, two different types of electromagnetic transients are of primary concern for the design of fire protection and life safety systems: Source Region Electromagnetic Pulse (SREMP) and High Altitude EMP (HEMP). The techniques for providing protection against these stressing environments have been developed and tested over the course of several decades and have reached a reasonable state of maturity. The basic document that provides interface standards for designing these techniques and testing them are contained in MIL-STD-188-125-1.

References for this Appendix include:

1. "Report of the Commission to Assess the Threat to the U. S. from Electromagnetic Pulse (EMP) Attack" Volume 1 Executive Report of 2004.
2. MIL-STD-188-125-1 "DoD High-Altitude Electromagnetic Pulse (HEMP) Protections for Ground-Based C4I Facilities Performing Critical Time-urgent Missions Part 1 Fixed Facilities" of 17 July 1998.
3. NATO file No. 1460-3 "EMP Engineering Practices Handbook" of August 1988 and subsequent editions.

What the FPE and AHJ need to understand is that if EMP is a specified design threat, then special design features are needed to prevent disruption or damage to the fire protection and some life safety systems. In an EMP environment, there are two ways that a fire protection system can be damaged; i.e., the fire protection system itself could be inadequately protected or another system could be inadequately protected that couples EMP energy into the fire protection system. This works both ways, i.e., an inadequately protected fire protection system can also couple EMP energy into other systems. Thus, if EMP is a specified design threat, the FPE needs to coordinate his design with an EMP protection specialist. If fire protection systems are not adequately EMP protected they cannot be expected to function after an EMP event. As stated in Section 2.9 (EMP Protection) UGF fire protection design engineers and facility operators should expect to lose some or all fire protection and life safety system functions if an EMP event occurs and those systems are not designed specifically to survive that WMD threat. The following provides a brief introduction into what EMP is and what the common techniques are to protect against it.

Source Region EMP (SREMP)

SREMP occurs when a nuclear detonation is at or near the earth's surface. The X-rays released by the fission or fission/fusion process have a short mean free path in air and are absorbed by the air molecules over a short distance creating the fireball. However, the gamma-rays released by the weapon or created by the interaction of neutrons with the surrounding media can produce significant current flows in the atmosphere at much greater ranges. The gamma-rays interact with the air molecules and atoms through a process called Compton scattering where the gamma-ray collides with an electron and transfers enough energy to free the electron from the atom or molecule. This recoil electron moves away from the detonation point leaving behind a positively charged atom or molecule. The area around the detonation point with the high electron density created by Compton and electron scattering is called the source (deposition) region. Extremely high current flows are created in the source region when the electrons return to the positively charged ions. This is especially true for a low resistance path such as a metal cable, pipe or duct, which can collect 10s to 100s of kiloamps with duration which can last for milliseconds. The area within the source region is mainly of concern for physically hardened facilities. Outside the source region, a radiated field occurs with field strengths of kilovolts/meter which fall off as one over the distance from the detonation point. These energy levels are many orders of magnitude greater than the operational voltages and currents of any digital equipment.

High Altitude EMP (HEMP)

HEMP results from the detonation of a nuclear warhead at altitudes of about 40-400 kilometers above the earth's surface. The immediate effects of EMP are disruption of, and damage to electronic systems and electrical infrastructure. EMP is not reported in the scientific literature to have direct effects on people in the parameter range (i.e., volts/meter on the ground) of present interest. There are three types of HEMP component fields: E1, E2 and E3. E1 is measured in kilovolts/meter, E2 is measured in volts/meter and E3 is measured in volts/kilometer.

The first component, E1, is a free-field energy pulse with a rise-time measured in the range of a fraction of a billionth to a few billionths of a second. It is the high voltage "electromagnetic shock" that disrupts or damages electronics-based control systems, sensors, communication systems, security systems, computers, and similar devices that operate at relatively low voltages. Its damage or functional disruption occurs essentially simultaneously over a very large area (i.e., approximately line-of-sight). For example, a detonation at 100 km (~62 miles) altitude can produce appreciable HEMP energy out to a range of ~1,120 km (~695 miles) from the detonation point. The HEMP amplitude, duration, and polarization are dependent upon the position of the exoatmospheric burst and observer relative to the earth's magnetic field lines.

The middle-time component, E2, covers roughly the same geographic area as the first component and is similar to lightning in its time-dependence. However, as compared to lightning it is far more geographically widespread and somewhat lower in amplitude. In general, the E2 component would not be an issue for fire protection and life safety systems that have existing protective measures for defense against occasional lightning strikes. The most significant risk is synergistic, because the E2 component follows a small fraction of a second after the first (E1) component's insult which has the ability to impair or destroy many protective and control

features meant for lightning protection. The energy associated with the E2 component thus may be allowed to pass into and damage systems.

The final major component of HEMP, E3, is a subsequent, slower-rising, longer-duration pulse that creates disruptive currents in long electricity transmission lines, resulting in damage to electrical supply and distribution systems connected to such lines. The sequence of E1, E2 and then E3 components of HEMP is important because each component can cause damage, and the later components can be increase the damage as a result of the earlier damage.

EMP Interactions and Protection Techniques

Copper power and communications/signal cables connected to sensitive, critical electronics can act as antennas and collect EMP energy and conduct it to sensitive electronics resulting in transient upset, permanent upset, or damage. Similar effects result when metallic pipes or ducts conduct EMP energy into a facility and the resulting energy field induces high transient voltages and currents in nearby power and conducting communications/signal cables. The lower the operating voltage for sensitive electronics, controls and so on, the more vulnerable it is to EMP insults. Concern for vulnerable equipment led to the development of the following protection techniques.

Tailored Hardening

Older systems may be protected by an earlier design philosophy called tailored hardening which has since been discredited. If the FPE encounters a tailored hardening design, the following describes that earlier design. Invariably, tailored hardening ignored fire protection and life safety system. Consequently, in a UGF that used tailored hardening, the fire protection and life safety systems cannot be expected to function after an EMP event. Tailored hardening was designed by estimating damaging voltage and current transient levels that would be collected by the "antennas" connected to sensitive devices. Then, the designer used current limiting devices, such as surge arresters, in some cases coupled with filters, to reduce the energy at the interface to a level that would not induce damage. This approach was much the same as providing lightning protection using different types of surge arresters, such as Metal Oxide Varistors (MOVs), gas tube arresters and spark gaps. Tailored Hardening involved installing protection on penetrating cables at the facility and on individual electronic boxes to limit damaging transients. However, this was not a high confidence approach for providing protection since there was no uniform protocol for verifying protection effectiveness. It was also difficult, at best, to maintain the perceived protection since system changes, e.g., upgrades or modifications made to the facility or to electronic boxes, could obviate protection effectiveness by providing new antennas to collect the EMP energy and perhaps exceed the design protection.

High Confidence EMP Protection

For over two decades the preferred approach for protection has been to build an "Electromagnetic Barrier" or Shield and provide protection at the barrier boundary to provide high confidence, verifiable protection. The approach consists of building a six-sided shielded metallic volume, essentially a global Faraday cage around the protected volume, to house

mission critical equipment and necessary support equipment. The designer then places equipment such as diesel generators and Heating Ventilation and Air Conditioning (HVAC) equipment within the shield, and at the shield boundary provides protection for all barrier penetrations. The shield boundary is where fire mains, fire alarm systems, life safety systems, smoke detection equipment and smoke exhaust ducts penetrate the shield and need those special EMP protection designs. For power penetrations, the standard technique is to provide a filter on each phase preceded by a surge arrester, such as an MOV to reduce the incoming transients to a level that will not damage the filter. Thus, the residual transient is reduced to a level within the safe operating range of the critical equipment. An alternative approach is to use a motor-generator set with the motor on the outside of the shield connected to a generator on the shield interior via a dielectric shaft which is fed through an appropriately sized waveguide beyond cutoff (WBC) that takes into account the dielectric constant of the shaft.

Various power, water, communication/signal cables need to penetrate an EMP shielded volume in order to provide services. There are two ways to protect penetrating systems from conducting an EMP into the protected volume. For conducting systems, such as fire mains, the pipe is circumferentially welded to the shield and a dielectric section of the pipe is installed in the metallic pipe a short distance outside the shield. The WBC array installed at the shield penetration should take into account the dielectric properties of water. For communications/signal cables that must penetrate the EMP shield the current protection approach is to maximize the use of fiber-optic cables, without metal strengthening members or a metal rap on the outside of the bundle. The fiber-optic cables are fed through pipes, i.e., WBC pipes that are circumferential welded to the shield at the penetration point. WBC structures are the universal way to permit a non-conducting cable to penetrate the EMP shield. WBC are essentially round or square pipe welded to the shield (and together if there is an array of pipes) through which non conducting communications/signal cables, such as fire alarm system fibers can penetrate the shield. The diameter and length of WBC pipes are sized to provide the level of EMP protection required by the facility. For shielded structures the design of the WBC features must take into account the requirements for personnel entry and egress without degrading the overall protection as well as air intake and exhaust, water, fuel sewerage and other necessary penetrations including fire protection and life safety related systems. In addition, once constructed, the EMP protection should be verified through testing. This design philosophy, i.e., High Confidence EMP Protection and the associated verification tests are articulated in MIL-STD-188-125-1. The testing protocol is provided in Appendix A of MIL-STD-125-188-1.

Hardness Maintenance / Hardness Surveillance (HM/HS)

HM/HS procedures have been developed to assure that the protection does not degrade over the life cycle of the facility. Depending on the EMP protection design, the surveillance and maintenance procedures could involve periodic testing for surge arresters and filters, conducting periodic SELDS testing to assure that shield welds are not deteriorating, and visual inspection of WBC penetrations to assure that no metallic penetrations have been fed through the WBC. The frequency of inspections and testing depends on the type of protective features at the shield boundary. HS recertification testing shall be performed at intervals not exceeding seven years using the testing protocol provided in Appendix A, MIL-STD-188-125-1.

Glossary of Abbreviations

Abbreviations that are not written out in the text, such as DoD, DTRA or WMD are common knowledge for the intended reader

ABC	A fire extinguisher used for Class A fires (wood, paper, fabrics) Class B fires (flammable liquids) and Class C fires (electrical)
A & E	Architect & Engineer
AFFF	Aqueous film-forming foam
AHJ	Authority Having Jurisdiction
AHU	Air Handling Unit
ASCE	American Society of Civil Engineers
ASD	Aspirating Smoke Detector
AutoCAD	Computer-Aided Design (software by Autodesk, Inc.)
BAS	Building Automation System
BSA	Balance Survivability Assessment
CBR	Chemical, Biological & Radiological
CBRN	Chemical, Biological, Radiological & Nuclear
CE	Civil Engineer
CO	Carbon Monoxide
CO_2	Carbon Dioxide
C3I	Command, Control, Communications & Intelligence
C4I	Command, Control, Communications, Computers & Intelligence
DC	Damage Control
DC/RO	Damage Control **/** Recovery Operations
DECON	Decontamination
DHS	Department of Homeland Security
DoD	Department of Defense
EMP	Electromagnetic Pulse
EMS	Emergency Medical Services

EOC	Emergency Operations Center
EPO	Emergency Power Off
EWFD	Early Warning Fire Detection
FACP	Fire Alarm Control Panel
FACS	Fire Alarm Control System
F & ES	Fire & Emergency Services
FM-200	DuPont’s trade name for Heptafluoropropane (HFC-227ea) clean agent
FPE	Fire Protection Engineer
GIS	Geographic Information System
HEMP	High Altitude Electromagnetic Pulse
HM **/** HS	Hardness Maintenance **/** Hardness Surveillance
HQ	Headquarters
HVAC	Heating, Ventilation & Air Conditioning
H_2	Hydrogen
IBC	International Building Codes
IOC	Initial Operating Condition
ISO	International Organization for Standardization
ITM	Inspection, Testing and Maintenance
LCD	Liquid Crystal Display
Li (OH)	Lithium Hydroxide
LOAEL	Lowest Observed Adverse Effect Level
MIC	Microbiologically Influenced Corrosion
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MOV	Metal Oxide Varistor
MSHA	Mine Safety & Health Administration
NATO	North Atlantic Treaty Organization
NEC	National Electric Code
NEMA	National Electric Manufacturers Association
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health

NIST	National Institute of Standards & Technology
NOx	Nitrogen Oxides
ODP	Open Drip Proof
O_2	Oxygen
OFE	Owner Furnished Equipment
O & M	Operations and Maintenance
OMSI	Operations & Maintenance Support Information
OpSec	Operations or Operational Security
OSHA	Occupational Safety and Health Administration
PA	Public Address
POL	Petroleum, Oil and Lubricants
PVC	Polyvinyl Chloride
RF	Radio Frequency
SCADA	Supervisory, Control and Data Acquisition
SCBA	Self-Contained Breathing Apparatus
SELDS	Shield Enclosure Leak Detection System
SPVs	Single Point Vulnerabilities
SREMP	Source Region Electromagnetic Pulse
TCF	Technical Control Facility
TEFC	Totally Enclosed Fan Cooled
UFC	Unified Facilities Criteria
UGF	Underground Facility
UPS	Uninterruptible Power Supply
UVA	Underground Vulnerability Assessment
VEWFD	Very Early Warning Fire Detection
VIED	Vehicle Improvised Explosive Device
WBC	Waveguide Below Cutoff
WMD	Weapons of Mass Destruction
WP	Warsaw Pact
WWII	World War Two

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